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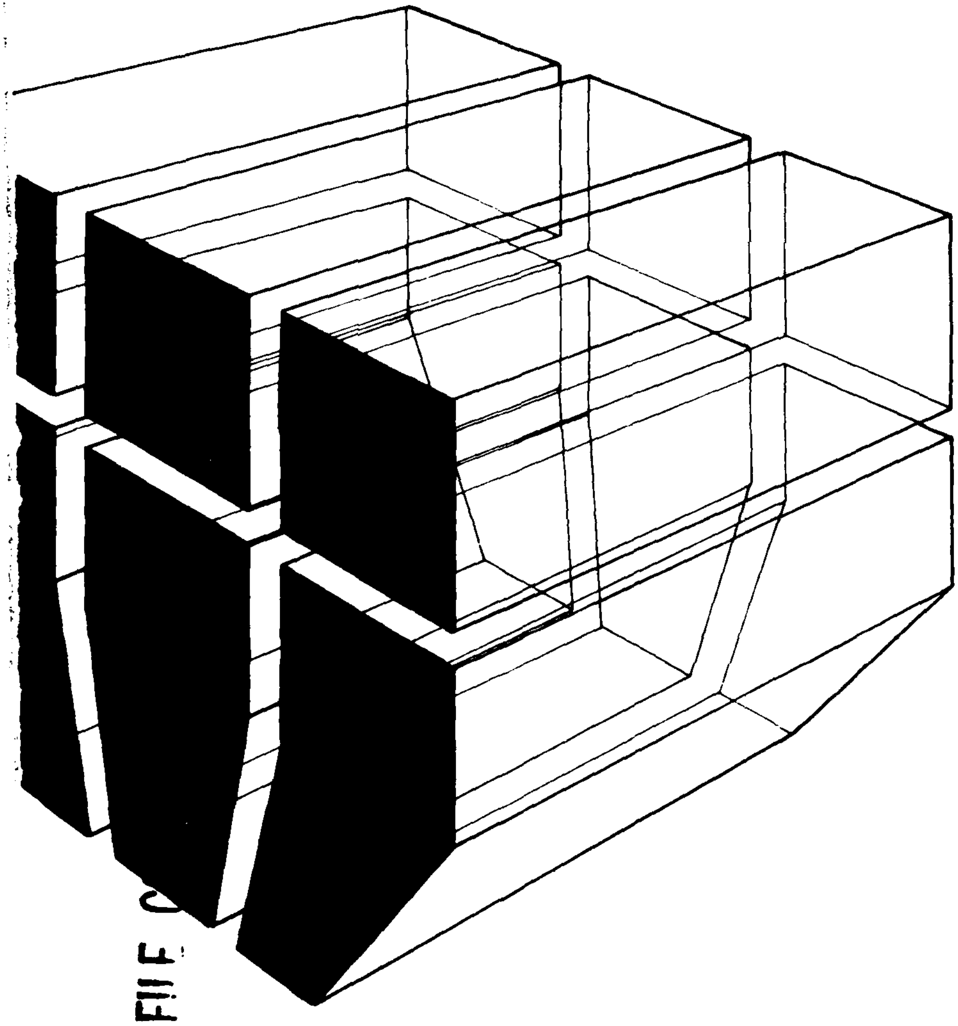
TECHNICAL REPORT M-313
April 1982
Laboratory Evaluation of EMP/EMI Shielded
Enclosure Performance and Design Standards

STUDY OF EMI/RFI SEALS ON SHIELDED-ENCLOSURE PERSONNEL ACCESS DOORS



by
Roy A. Axford

CERL

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This study investigated the relative shielding capabilities of three EMI/RFI door seal designs: (1) the double-mesh gasket, (2) the wiping compression contact fingerstock gasket, and (3) the recessed fingerstock contact (knife edge). The effects of aging and wear on the doors when no maintenance was applied and the effectiveness of the manufacturers' recommended maintenance procedures were investigated. The effects of electroplating tin on door seal contacts were also determined.

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It was found that the designs studied degrade quickly with time and use and require periodic maintenance to maintain seal quality. The beryllium-copper fingerstock contact design appeared to last longest when properly maintained. All designs showed rapid degradation under normal or infrequent use if no maintenance was provided. It was also found that recommended maintenance procedures improved shielding dependably only up to 80 dB. It was noted that electroplating of tin onto contact surfaces did not significantly improve shielding capabilities of the beryllium-copper contacts but did improve those of the double-mesh gasket door.

FOREWORD

This investigation was performed for the Directorate of Military Programs, Office of the Chief of Engineers (OCE), under project 4A762719AT40, "Mobility, Soils and Weapons Effects"; Technical Area AO, "Weapons Effects and Protective Structures"; Work Unit 015, "Laboratory Evaluation of EMP/EMI Shielded Enclosure Performance and Design Standards." The applicable QCR is 1.03010. The OCE Technical Monitor was Mr. Paschal Brake, DAEN-MPE-E.

This investigation was performed by the Engineering and Materials Division (EM), U.S. Army Construction Engineering Research Laboratory (CERL). Dr. Robert Quattrone is Chief of EM.

The assistance of the following CERL personnel is acknowledged: Messrs. Ray McCormack and Paul Nielsen for their guidance in the preparation of this report, and Matthew Sale for his assistance in gathering shielding data and electroplating EMI/RFI gaskets. Appreciation is expressed to Greg Cekander and Stanley Hutchinson of CERL for their assistance in gathering shielding data.

COL Louis J. Circeo is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

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FIGURES (cont'd)

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STUDY OF EMI/RFI SEALS ON SHIELDED-ENCLOSURE PERSONNEL ACCESS DOORS

1 INTRODUCTION

Background

Military forces are increasingly reliant on complex electronic equipment to complete their missions successfully. As electronic equipment grows more complex, it generally becomes more susceptible to electromagnetic interference (EMI) and radio frequency interference (RFI). Consequently, sensitive electronic equipment is often placed in EMI/RFI shielded enclosures (tactical shelters and screen rooms, for example) to protect it from unwanted electromagnetic energy.

The U.S. Army uses electromagnetic shielding in many military construction projects, including weapon control facilities (e.g., the SAFEGUARD Anti-Ballistic Missile facilities), underground secure command centers, secure communications facilities, command and control center buildings on military bases, electronic maintenance shops, and electronic research and development facilities.

When shielded enclosures are built, discontinuities in the shield cannot be avoided at panel joints, cable entry points, ventilation openings, and personnel access doors. EMI/RFI leakage at these discontinuities can threaten the integrity of the enclosure's shielding effectiveness. One of the most difficult tasks for the designer of a shielded enclosure is to provide a reliable EMI/RFI seal around the personnel access door. This seal is subjected to continual wear throughout the lifetime of the enclosure and is particularly vulnerable to adverse environmental conditions.

Although an EMI/RFI door seal may conform to shielding specifications immediately after it is installed, it is likely that its ability to provide good electrical contact around the door will degrade in time due to mechanical stresses and/or corrosion. Regular maintenance and even periodic replacement of the EMI/RFI seal contacts may be necessary to insure continued shielding integrity.

Several designs for EMI/RFI seals on personnel access doors are available; however, little has been done to evaluate their relative shielding performance or durability. Therefore, the U.S. Army Construction Engineering Research Laboratory (CERL) studied the effects of aging, adverse environmental conditions, and manufacturers' recommended maintenance procedures on different EMI/RFI seal designs for personnel access doors.

Objective

The objectives of this study were to:

1. Assess the relative shielding capabilities of three different EMI/RFI door seal designs.

2. Assess the effects of aging and wear on the three door seal designs when no maintenance procedures were applied.

3. Assess the benefits and shortcomings of manufacturers' recommended maintenance procedures, when available, for the door seal designs.

4. Determine how electroplating tin on door seal contacts might affect the shielding effectiveness of the EMI/RFI seal. Tin is a soft metal that provides a mechanical blend on closure of the contacts. Also, tin oxide, the product of the corrosion of tin, is conductive.

Scope

This study is concerned with EMI/RFI door seal designs found on both shielded tactical shelters and permanent, fixed, shielded facilities. The study has considered EMI/RFI shielding aspects of door seals, but has not directly investigated electromagnetic pulse (EMP) hardening.

The door seal designs studied included one that used mesh gasket contacts and two that used beryllium-copper fingerstock contacts. Spira contact designs and air-expandable doors were not studied. The effects of aging were studied for contacts supplied by manufacturers, but not for contacts that had been plated with tin after installation.

Approach

Laboratory testing was used to evaluate EMI/RFI door seal designs under various conditions. The effects of aging, moisture, wear, maintenance procedures, and tin electroplating on the integrity of the EMI/RFI seals were studied.

Mode of Technology Transfer

It is anticipated that this study will impact on the revision of Technical Manual TM 5-855-5, *Nuclear Electromagnetic Pulse (NEMP) Protection.*

2 EMI/RFI DOOR SEAL DESIGNS

To provide an EMI/RFI seal around a personnel access door, good electrical contact must be maintained at all points around the edges between the door jamb and the door itself. Three different designs were investigated for this study, representative of EMI/RFI door seal state of the art.

Figure 1 is a schematic diagram of the double-mesh gasket. This door is mounted on a prototype, 80-dB, S280 tactical shelter (Figure 2) with all-welded wall-panel seams. The personnel access door is the only penetration through the shelter, so it is the main source of EMI/RFI leakage. Figures 3 and 4 show close-ups of the door edge and door jamb, respectively. The metal mesh gasket is constructed of tin on copper on steel. Steel is used for strength, copper for high conductivity, and tin for low contact resistance and corrosion resistance. (Tin oxide is conductive.) The knife edge that mates with the mesh gasket is made of aluminum coated with alodine.

Figure 5 is a schematic diagram of the second type of EMI/RFI door seal that was investigated. This contact arrangement is known as a wiping/compression contact fingerstock gasket (see Figure 6). Its name is derived from the fact that one row of fingerstock makes wiping contact with the door jamb, and the other row makes compression contact. Figures 7 and 8 show close-ups of the door edge and door jamb. The fingerstock strips are made of a beryllium copper alloy and are continuously soldered to the door. Figure 9 shows a view of the door contacts and door jamb along the hinge side of the door.

Figure 10 is a schematic diagram of the third type of EMI/RFI door seal investigated. This design, known as a recessed fingerstock contact design or "knife edge," is found on the door shown in Figure 11. Beryllium copper fingerstock contact strips are recessed in the door frame and make contact with a brass knife edge on the door when it is closed. Figures 12 and 13 show close-ups of the knife edge door and the recessed contacts.

Figures 14 and 15 show the shielded room on which both the wiping/compression door and the knife edge door were mounted. The room is a bolt-together, double-wall-aluminum structure with all of the wall panel seams soldered. The soldered seams provide more than 110 dB of shielding to a magnetic field of 150 kHz. Thus, all significant EMI/RFI leakage enters the room at the personnel access doors. Furthermore, the wiping/compression and knife edge doors are mounted on opposite walls of the room.

3 EMI/RFI TEST PROCEDURES

Shielding effectiveness measurements were made for magnetic fields at 200 kHz, 2 MHz, and 20 MHz, and for plane waves at 2.5 GHz. No measurements were made for electric fields. In most of the investigations, magnetic field measurements at 200 kHz and plane wave measurements at 2.5 GHz were enough to show the effects of experimental parameters.

Magnetic field measurements were taken at test points along the door seals with 12-in. (304.8-mm)-diameter loop antennas positioned in the coaxial orientation spaced 12 in. (304.8 mm) from either side of the wall (see Figure 16). Twelve test points were used on all doors (except where noted otherwise) and are labeled as shown in Figure 17.

The plane wave measurements were made using horn antennas positioned 1 m from either side of the shelter wall opposite the test point (see Figure 18). This technique was used for making plane wave measurements since it isolates test points along the seam more than the procedures called for in MIL-STD-285[1] or IEEE 299.[2] Furthermore, it is a more severe test than the IEEE 299 procedure. Figure 19 compares measurements taken with the horns positioned opposite the test point (moving transmitter) and measurements made with the IEEE 299 procedure (stationary transmitter). (Due to reflections and standing waves, it is hard to obtain good repeatability for plane wave measurements at 2.5 GHz.)

The instrumentation used in the shielding effectiveness measurements is shown in Figure 20 and listed in Table 1.

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[1] *Military Standard Attenuation Measurements for Enclosures, Electromagnetic Shielding, for Electronic Test Purposes, Method of*, MIL-STD-285 (U.S. Government Printing Office, June 1956).

[2] *Proposed IEEE Recommended Practice for Measurement of Shielding Effectiveness of High Performance Shielding Enclosures*, IEEE 299 (Institute of Electrical and Electronic Engineers [IEEE], June 1969).

Table 1
Shielding Effectiveness Measurement Instrumentation

200 kHz Magnetic

- Wavetek 147 Signal Generator
- EIN Model 310 L RF Power Amplifier
- Stoddart NM-12AT Radio Interference and Field Intensity Meter
- LP 105 12-in. Loop Antenna
- CFRL 12-in. Loop Antenna (High Power, Transmitting)

2 MHz, 20 MHz Magnetic

- Replace Stoddart NM-12AT with EMC25 Receiver

2.5 GHz Plane Wave

- Stoddart NM-65T Receiver
- Ailtech Model 189A Power Oscillator
- 6-in. by 8-in. Aperture Horns
- Sperry D44S2 Isolator

4 EMI/RFI DOOR SEAL TESTS AND TEST DATA

This chapter discusses the experiments carried out on the EMI/RFI doors to evaluate their shielding effectiveness, durability, and maintainability. It also examines the effect of electroplating tin onto the knife edge contacts of the double-mesh gasket door and onto the beryllium-copper fingerstock contacts and door jamb of the wiping/compression contact door.

Initially, all three doors were tested in the condition "as received" from the manufacturer. Figures 21 through 23 present the results of these initial tests at 200 kHz and 2.5 GHz for the double-mesh gasket, wiping/compression contact, and knife edge contact doors. All the doors are specified to pass 80 dB from 150 kHz to 10 GHz; however, in the "as-received" condition, only the knife edge door passed this specification at all test points, and then only at 200 kHz.

Ray Proof Corporation, the manufacturer of the wiping/compression and knife edge contact doors, also manufactures a cleaner (CL 100) and a conductive lubricant (LB 100) for the cleaning and lubrication of the beryllium copper contacts of their doors. The effects of these products on the wiping/compression contact door were investigated separately. Figures 24 and 25 show the shielding effectiveness of the wiping/compression door at 200 kHz and 2.5 GHz after cleaning, and after cleaning and lubricating. At 200 kHz, the cleaner alone brought the average shielding around the door up to 89 dB; addition of the conductive lubricant brought the average up to 104 dB. However, the effects of cleaning and lubricating at 2.5 GHz were not well defined. The cleaner improved the shielding effectiveness at this frequency over the "as received" condition at all but two test points; however, addition of the lubricant did not continue to improve the shielding effectiveness at 2.5 GHz.

The CL 100 cleaner was also used on the double-mesh gasket door. Figure 26 gives the results of this test for 200 kHz. The cleaner did not significantly improve the shielding of the double-mesh gasket door over the "as received" condition.

To investigate the relative contribution of the inner and outer gaskets of the double-mesh gasket door to the total shielding, shielding effectiveness was measured with each gasket isolated. This was done by taping one gasket so that it would not make contact with the door jamb. Thus, only the untaped gasket contributed to the EMI/RFI seal. Figure 27 shows the results of this test at 200 kHz. At most test points, the outer gasket contributes more to the total shielding than the inner gasket. Figure 28 gives the results of gasket isolation testing at 2.5 GHz. Here, the outer gasket clearly provides more shielding than the inner gasket at all test points. The data shown in Figure 28 were taken using the procedure outlined in IEEE 299, in which the transmitting horn was positioned 6 ft (1.8 m) from the center of the door. This plane wave procedure was used for this test only to more clearly show the relative effects of the gaskets. Consequently, the shielding effectiveness recorded where both gaskets were in contact is greater than shown in Figure 21.

The contacts on all three doors were cleaned again with CL 100 cleaner and allowed to stand for 4 months (8 June 1981 to 14 October 1981). During this time, the doors were opened and closed about once or twice per week, and thus subjected to minimal wear. Shielding effectiveness measurements were taken on all the doors to examine the effects of 4 months without maintenance. Figures 29 through 31 show the change in shielding effectiveness at 200 kHz observed over the 4-month period. On all three doors, the average shielding effectiveness fell by 10 dB or more at most of the test points. The double-mesh gasket had taken a compression set, thus reducing the contact pressure around the door seal. The wiping/compression contact and knife edge doors had developed a residue on the contacts, thus increasing contact resistance. Figure 32 shows the residue on the knife edge door.

To determine if the shielding effectiveness of the wiping/compression and knife edge doors was restorable, both were cleaned with CL 100 cleaner and lubricated with LB 100 lubricant. Figures 33 and 34 show the effects of this maintenance procedure for 200 kHz. For both doors, the shielding effectiveness was restorable to values well above 80 dB at all test points. Thus, no irreversible loss of shielding effectiveness was observed for the beryllium copper contact doors.

The double-mesh gasket door was subjected to a water test to determine the effect of moisture on its EMI/RFI seal. The gaskets were thoroughly moistened with tap water on 14 October 1981, and then the door was closed until it was retested on 19 October. The weather seal on the door had kept the EMI/RFI gasket wet for the 5 days. The door was allowed to stand open for another 9 days so that the gaskets could dry and then be retested. Figures 35 and 36 give these results. The dried gaskets had acquired a white residue which increased the contact resistance, thus lowering shielding at most points.

Similar moisture tests were conducted on the wiping/compression and knife edge contact doors. Water was sprayed on the lubricated contacts, and shielding effectiveness tests carried out 2 days later. Then the contacts were cleaned of the lubricant, moistened again, and tested 10 days later. Figures 37 and 38 give these results. Moisture adversely affected the shielding effectiveness of both beryllium-copper contact doors, even when the contacts were protected by the lubricant.

The double-mesh gasket door was then cleaned with CL 100 cleaner and the compression set in the gaskets was pinched out as much as possible. Shielding effectiveness measurements were taken at 200 kHz and 2.5 GHz (see Figures 39 and 40). Tin was then electroplated to the knife edge contacts of the double-mesh gasket door according to the procedure given in Appendix B. The intent of this procedure was to provide a lower contact resistance at the EMI/RFI seal. Tin was selected since it is soft and could be expected to provide a good blend as a contact. In addition, as tin corrodes, it produces tin oxide, which is conductive. Thus, the corrosion of a tin-plated contact should not degrade (increase) its contact resistance as much as other metals that produce non-conducting oxides. The resulting improvement in the EMI/RFI seal is shown in Figures 39 and 40.

Tin was electroplated to the fingerstock contacts and door jamb of the wiping/compression contact door (see Appendix B). However, the tin did not improve the EMI/RFI seal of this door, nor did the addition of LB 100 lubricant to the plated contacts. Figures 41 and 42 give these results for 200 kHz and 2.5 GHz.

5 CONCLUSIONS

The data presented in this report have illustrated the need for periodic maintenance of EMI/RFI seals around personnel access doors in shielded enclosures. Even though all the doors were specified to pass 80 dB from 150 kHz to 10 GHz, only one could do this in the as-received condition. All seal designs studied showed rapid degradation of shielding effectiveness under conditions of normal or infrequent use when no maintenance was provided. Moisture was also found to have an extremely detrimental effect on the shielding integrity of all the seals. The electroplating of tin onto contact surfaces improved the shielding of a double-mesh gasket design by about 10 dB (Figures 39 and 40), but did not significantly affect the shielding capability of beryllium-copper fingerstock contacts.

Although EMI/RFI door seals may comply with specifications initially, they degrade quickly with time and use (15 dB or more over a 4-month period with no maintenance) and require periodic maintenance to maintain seal quality (Figures 29, 30, and 31). Of the seals considered in this study, the beryllium-copper fingerstock contact designs, if properly cleaned and lubricated, appear to be maintainable over periods of years. However, the mesh gaskets studied are not as serviceable, do not respond well to cleaning, and will probably have to be replaced at least annually in order to maintain specified degrees of shielding.

For the wiping/compression and knife edge contact doors, use of the cleaner and lubricant supplied by the manufacturer dependably improved shielding effectiveness only up to 80 dB. No recommended maintenance procedures were provided for the double-mesh gasket design; the cleaner used for the other designs was tested for this door, but did not significantly improve shielding effectiveness.

In both the double-mesh gasket and single-mesh gasket (Appendix A) door seal designs, the highest leakage was consistently recorded along the door sill on the latch side. This problem has two probable causes: (1) reduced door closure force along this part of the seal, and (2) the exposed mesh gaskets' vulnerability to contamination by foreign matter from the feet of personnel.

APPENDIX A: SINGLE-MESH GASKET DOOR, TACTICAL SHELTER

As a followup to a previous study on tactical shelter shielding, a door with a single-mesh gasket EMI/RFI seal was tested.[3] The door was on a 60-dB S-280 tactical shelter that had been left outside in the weather since 15 March 1979 (Figure A1). Figures A2 and A3 show the door frame and door edge, respectively. The door has a rubber weather gasket (which seals quite well), and a single mesh EMI/RFI gasket just inside the weather seal. The mesh gasket mates with a flame-sprayed aluminum surface on the door frame, as shown in Figure A4.

The door had last been tested on 11 September 1979. Testing for this study was conducted on 29 October 1981 at eight points around the door at 200 kHz, 2 MHz, 20 MHz, and 2.5 GHz. Figures A5 and A6 present the test results from 11 September 1979 and 29 October 1981 for 200 kHz and 2.5 GHz. The results showed that the shielding effectiveness at 200 kHz has continued to deteriorate well below the 60-dB specification at all points tested. Although the plane wave data did not show continued deterioration around the door seal, the 60-dB specification was only met at two test points at this frequency.

Figure A7 presents the averages (over the test points) of the shielding effectiveness measurements taken at 200 kHz, 2 MHz, 20 MHz, and 2.5 GHz on 29 October 1981. The only test frequency for which the 2-½-year-old gasket met the 60-dB specification (on the average) was 20 MHz. Based on these results, it appears that a single-mesh gasket is not desirable for use over a long period of time.

[3] R. G. McCormack, C. Hahin, R. Lampo, and P. Sonnenburg, *Study of EMI/RFI Shielding of Tactical Shelters* ESL TR-80-24/AD-B054 597L (Engineering Services Laboratory Department of the Air Force, April 1980).

APPENDIX B: ELECTROPLATING PROCEDURES

The EMI/RFI seal contacts were brush-electroplated using Liquid Development Company, Inc., solutions and suggested plating procedures.

Double-Mesh Gasket Plating Procedure

1. Surfaces to be plated were lightly sanded to remove aladine coating and aluminum oxide. The surfaces were then cleaned with acetone.

2. Surfaces were "Electrocleaned" with L.D.C.-01 Electroclean solution at 10-V forward polarity and rinsed with water.

3. The surfaces were etched with L.D.C.-02 activator and etch solution at 12-V reverse polarity to remove all remaining oxidation and to allow plating solution to adhere to the aluminum. Surfaces were then rinsed with water.

4. The surfaces were preplated with L.D.C. #2801 nickel solution to obtain initial adhesion. The tin solution adheres to the nickel more readily than to the aluminum.

5. Surfaces were rinsed with water, plated with tin alkaline solution (L.D.C. #5001) at 12-V forward polarity, and rinsed again with water before testing.

Beryllium-Copper Contacts Plating Procedure

1. Surfaces were thoroughly cleaned with Ray Proof CL 100 cleaner, followed by cleaning with acetone to remove dirt and lubricant.

2. The surfaces were lightly sanded with medium-grit emery cloth to remove oxidation. They were then cleaned again with acetone.

3. The surfaces were "Electrocleaned" with L.D.C.-01 electrically activated cleaning solution, using 12-V forward polarity (door negatively charged, cleaning tool positively charged).

4. The surfaces were rinsed with water to remove any remaining solution.

5. The fingerstock and door jamb were plated with L.D.C. 5001 tin alkaline solution with 10- to 12-V forward polarity.

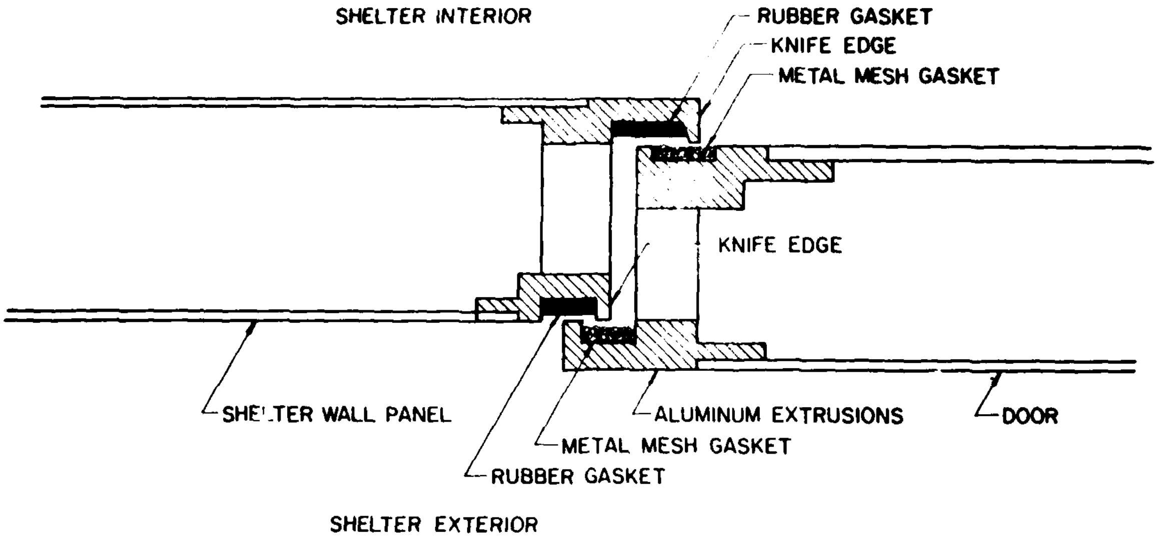

Figure 1. Schematic diagram of double-mesh gasket door seal.

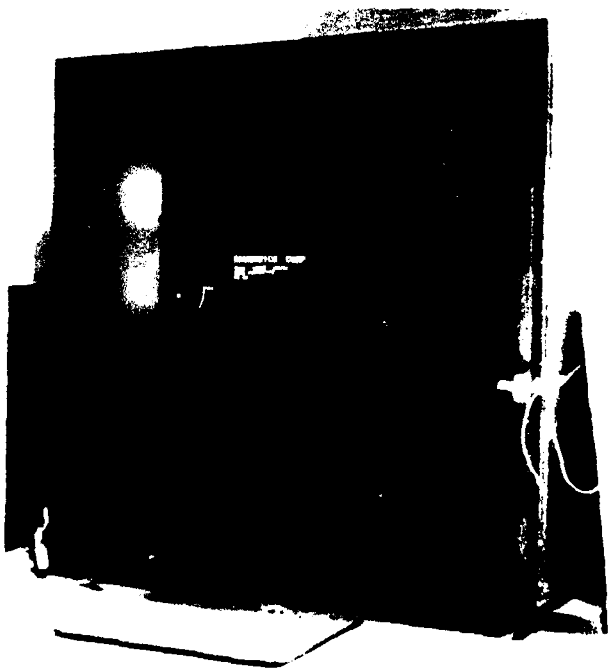

Figure 2. S280 shelter prototype with double-mesh gasket door.

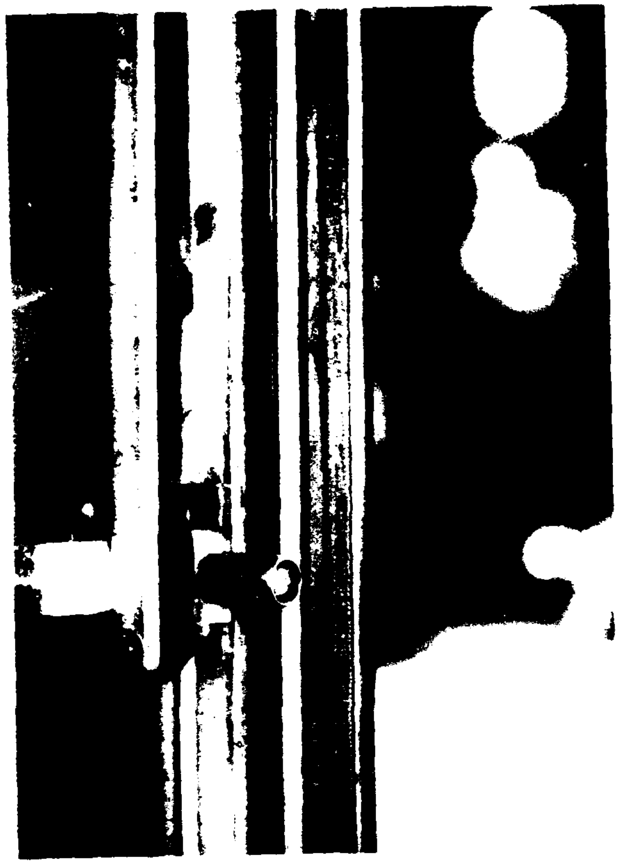

Figure 3. Double-mesh gasket door edge.

Figure 4. Double-mesh gasket door jamb

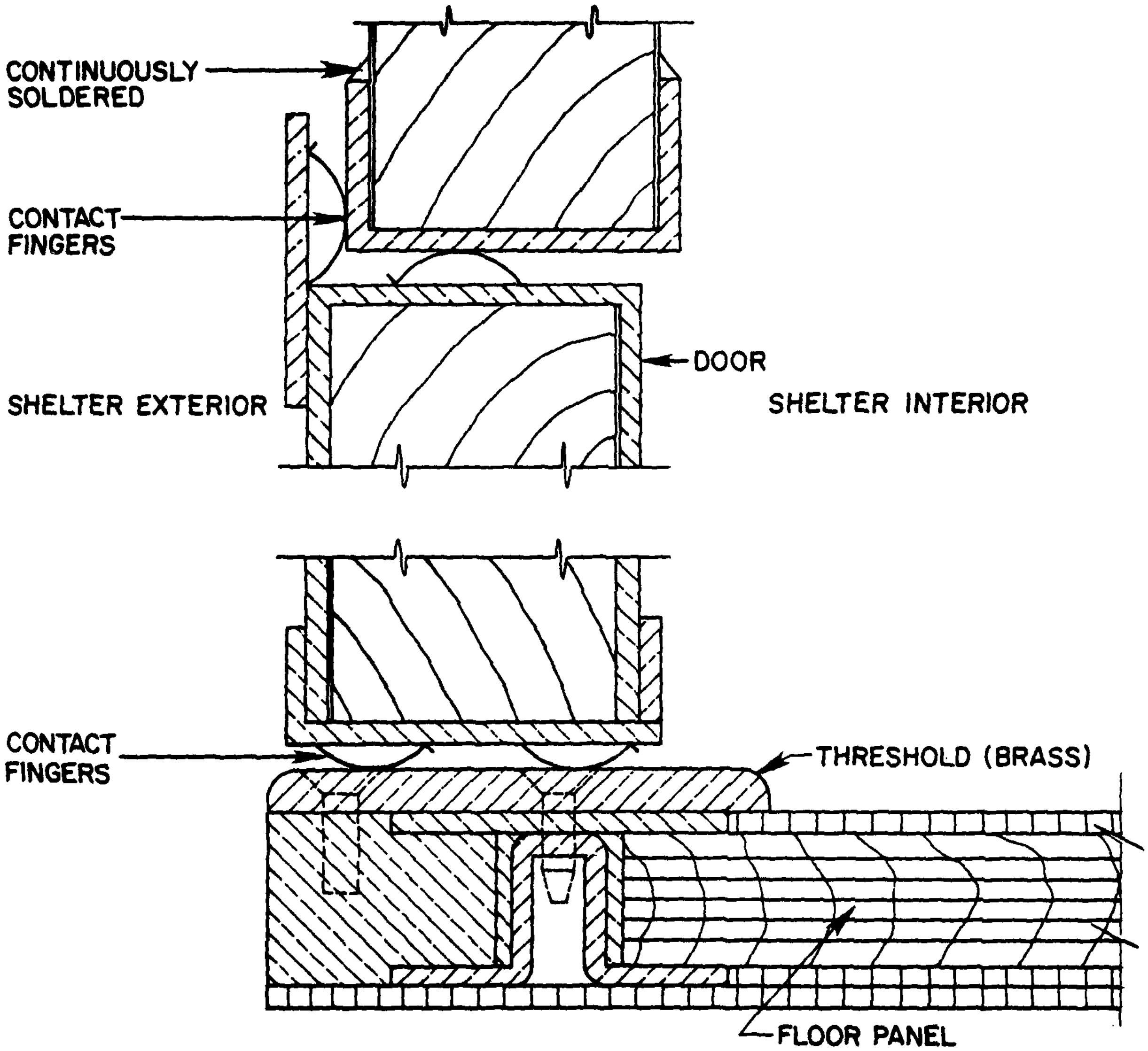

Figure 5. Schematic diagram of wiping/compression contact fingerstock gasket door seal.

Figure 6. Personnel access door with wiping/compression contact door seal.

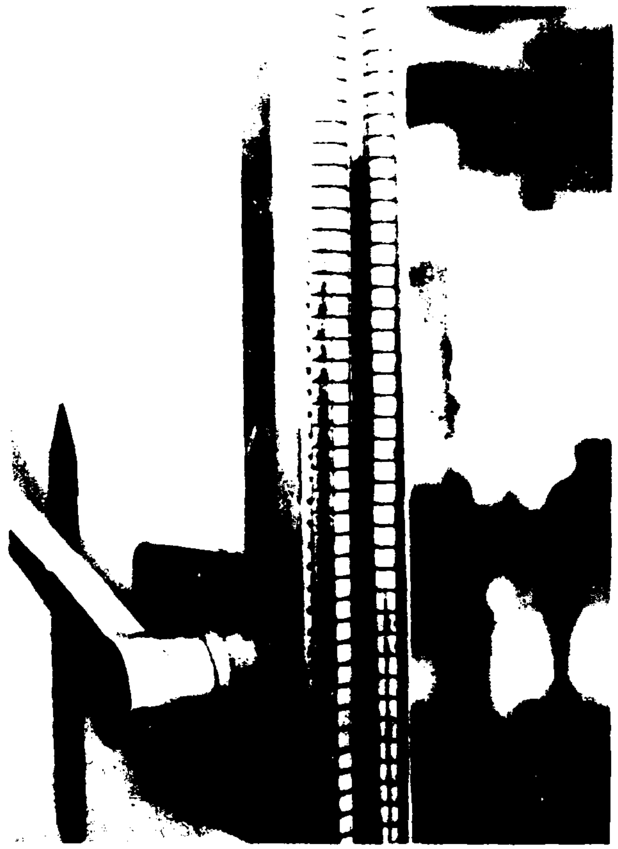

Figure 7. Wiping/compression fingerstock gasket door edge.

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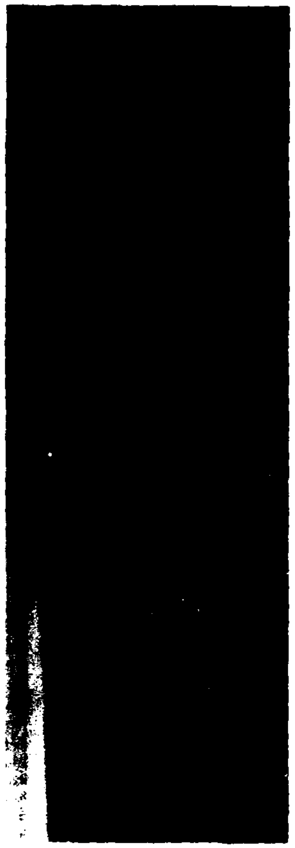


Figure 8. Wiping/compression fingerstock gasket door jamb.

Figure 9. Wiping/compression fingerstock gasket door edge and jamb.

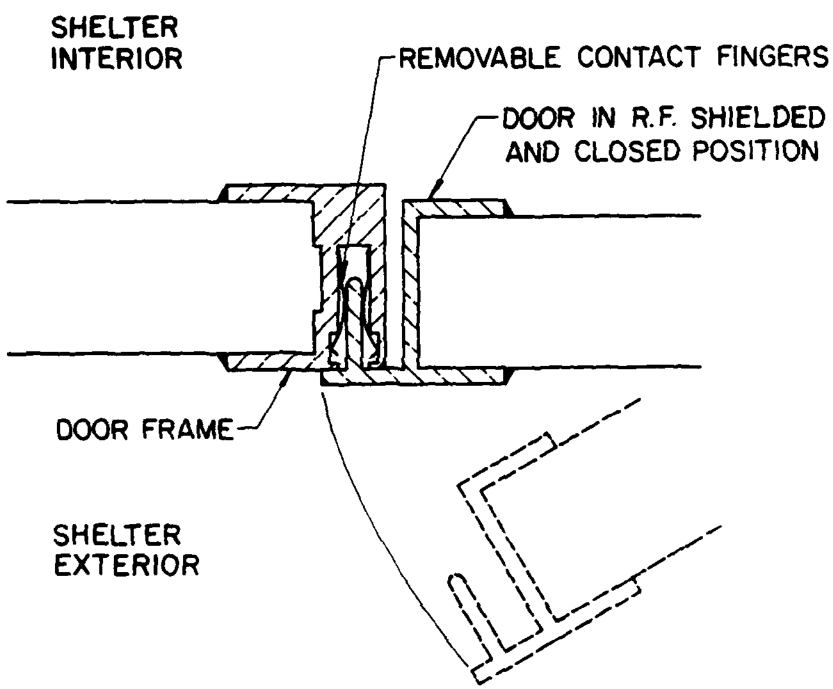


Figure 10. Schematic diagram of knife edge contact door seal.

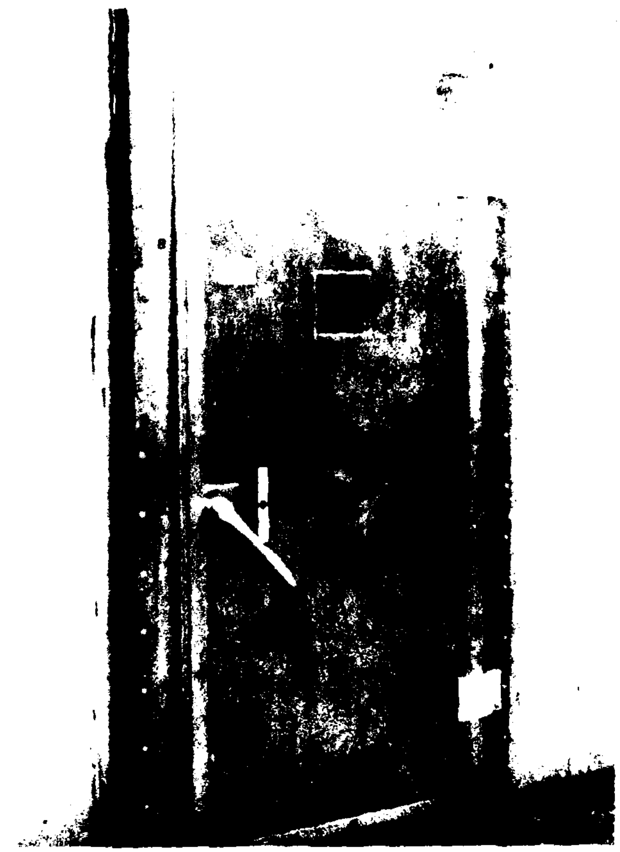


Figure 11. Personnel access door with knife edge contact seal.

Figure 12. Knife edge door edge.

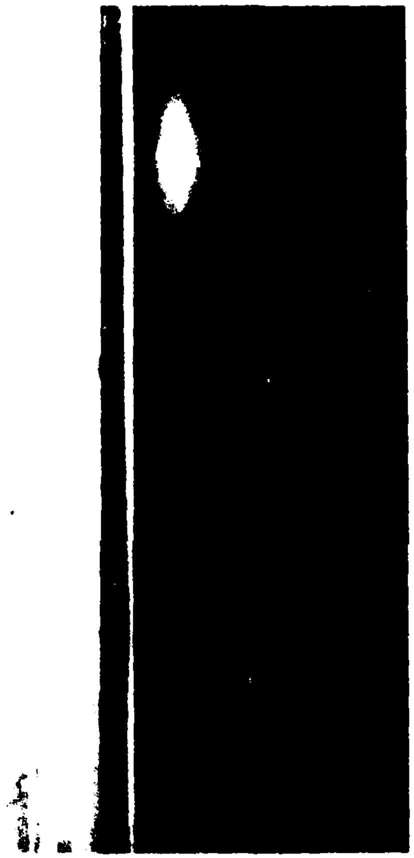


Figure 13. Knife edge door jamb with recessed fingerstock contacts.

Figure 14. View of shielded room with wiping/compression and knife edge contact doors.

Figure 15. View of shielded room with wiping/compression and knife edge contact doors.

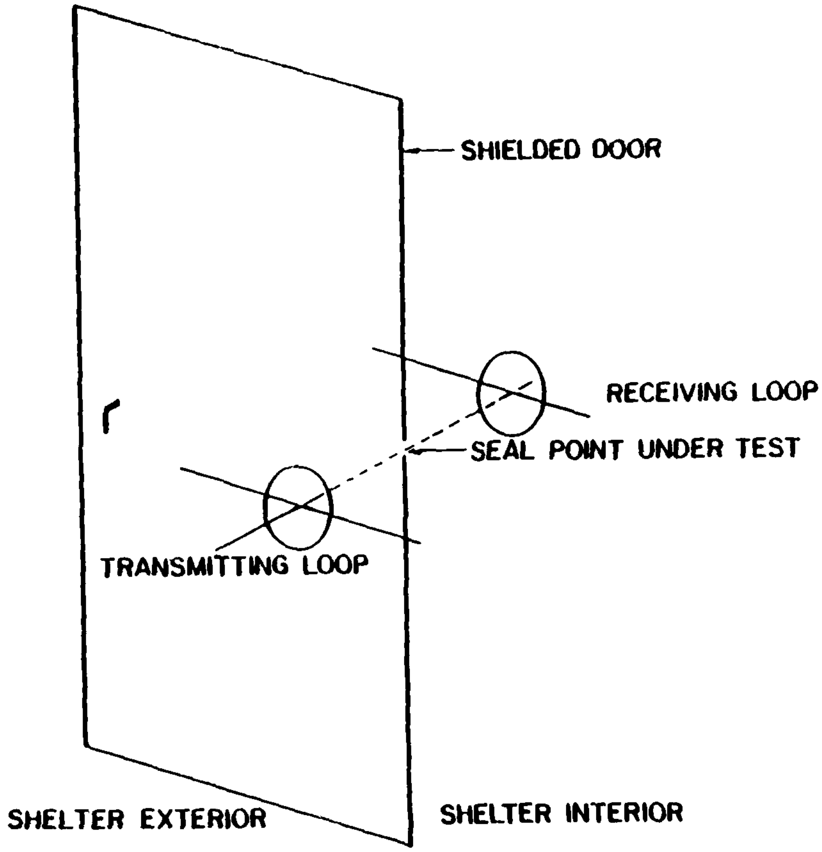


Figure 16. Orientation of loop antennas for magnetic field tests (200 kHz, 2 MHz, and 20 MHz).

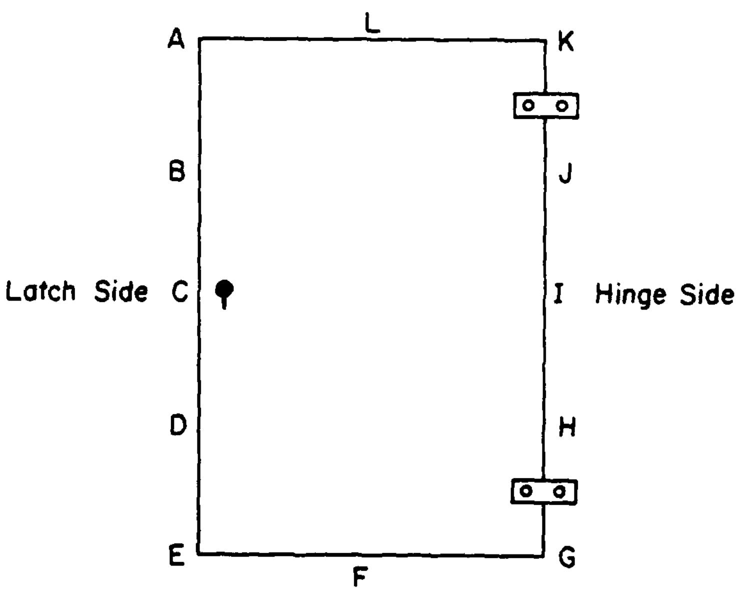


Figure 17. Test points for shielding effectiveness measurements.

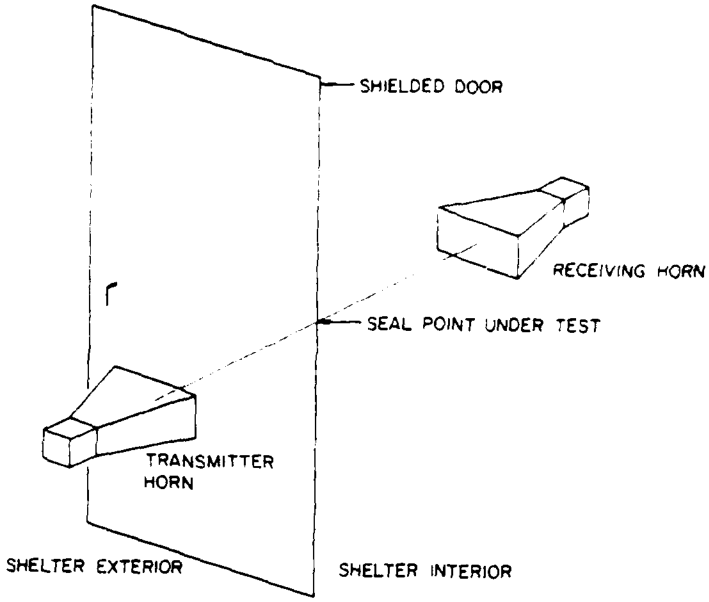


Figure 18. Orientation of horn antennas for plane wave field tests (2.5 GHz).

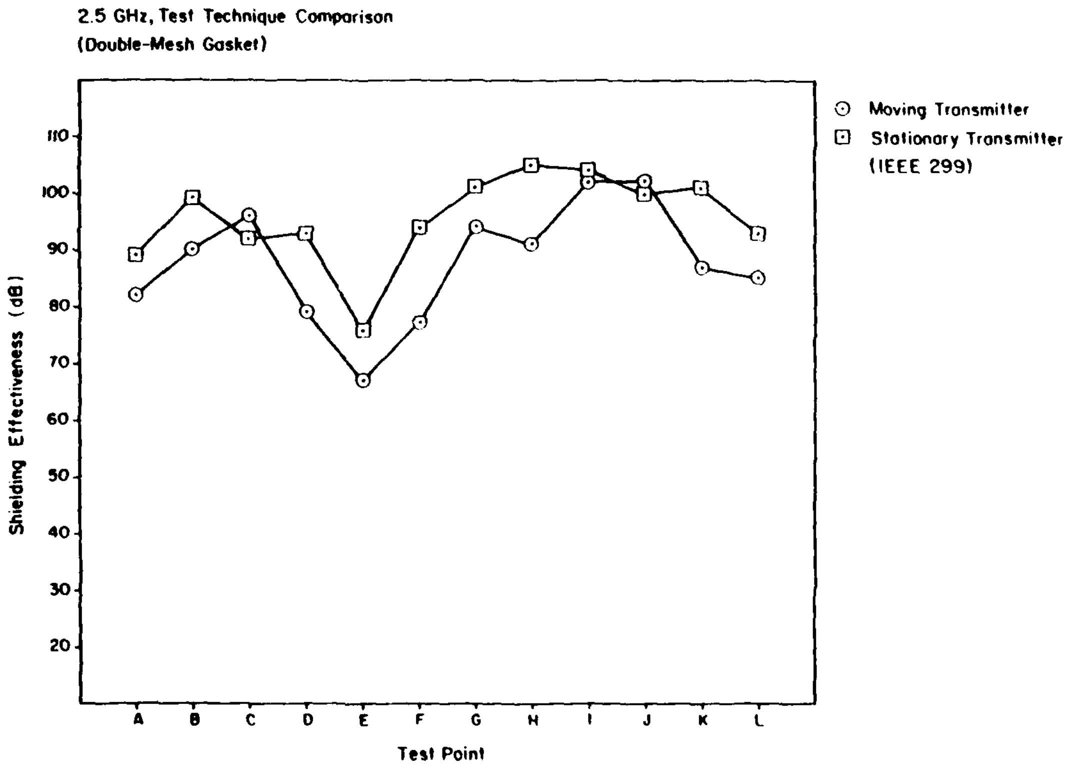
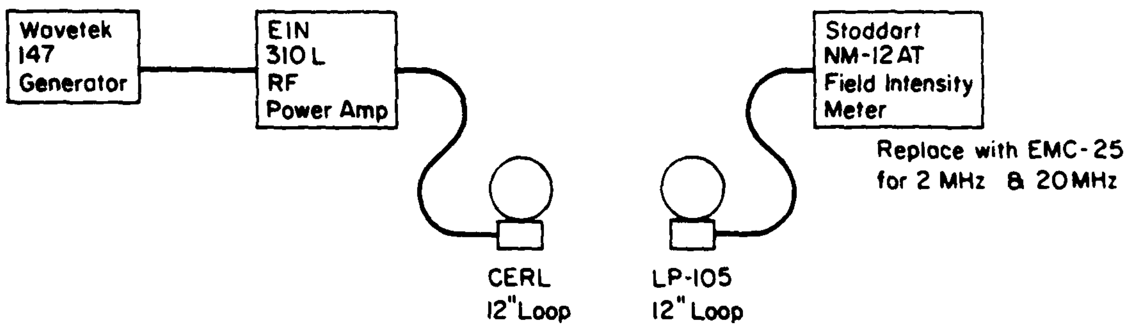


Figure 19. Shielding effectiveness measured on double-mesh gasket door with moving and stationary transmitting horns (2.5 GHz).

Magnetic Field Shielding Effectiveness Measurement Equipment



Plane Wave Shielding Effectiveness Measurement Equipment

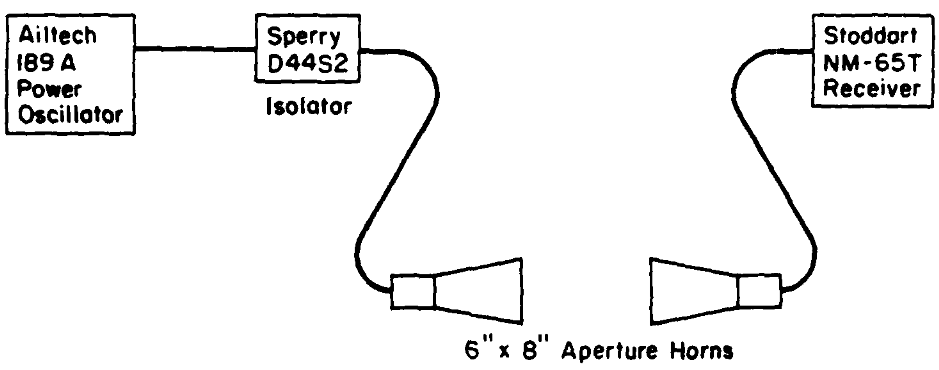


Figure 20. Shielding effectiveness measurement equipment.

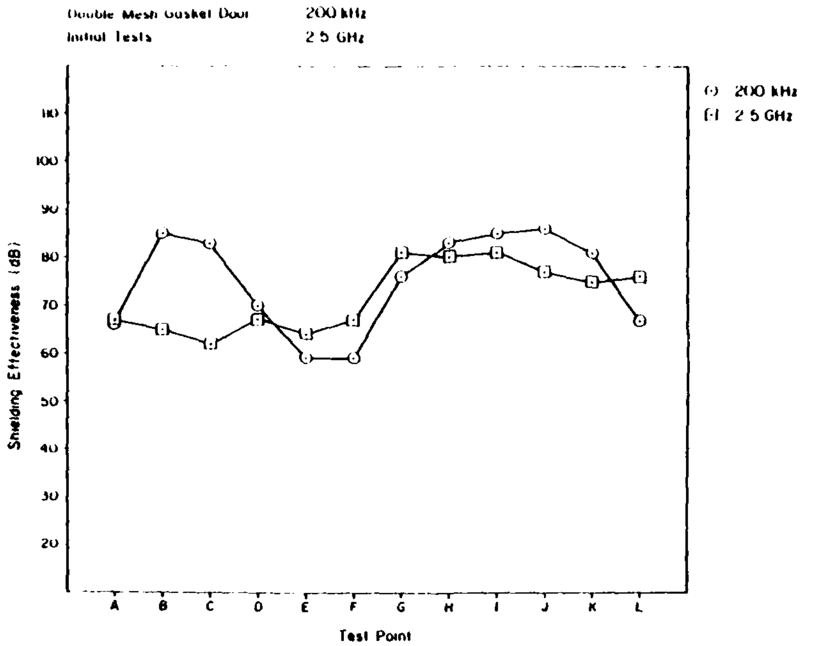


Figure 21. Shielding effectiveness of double-mesh gasket door, initial tests (200 kHz, 2.5 GHz).

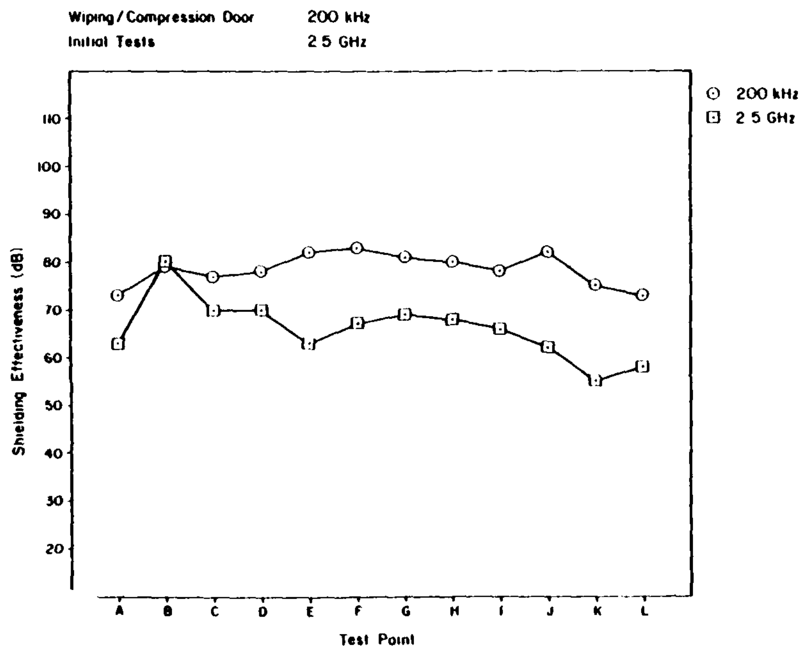


Figure 22. Shielding effectiveness of wiping/compression contact door, initial tests (200 kHz, 2.5 GHz).

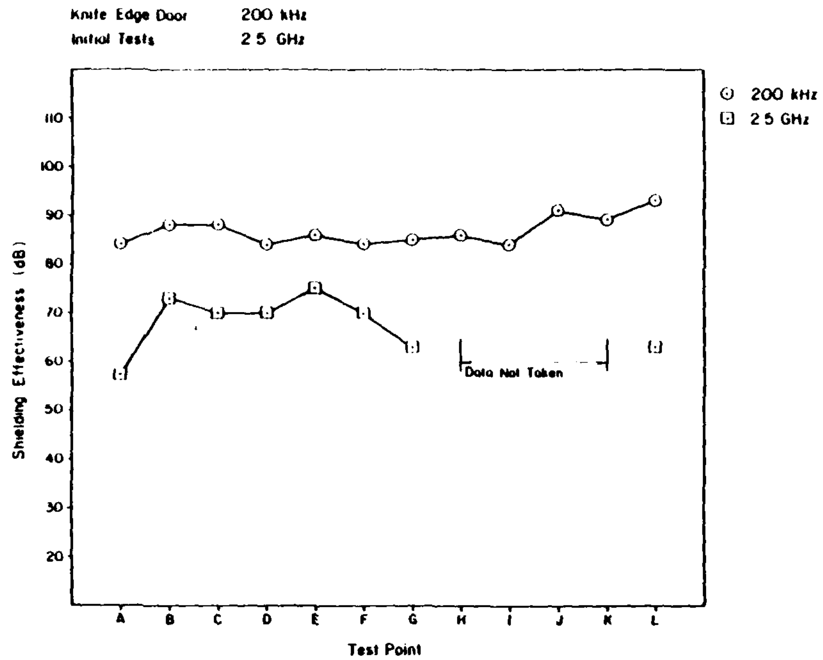


Figure 23. Shielding effectiveness of knife edge contact door, initial tests (200 kHz, 2.5 GHz).

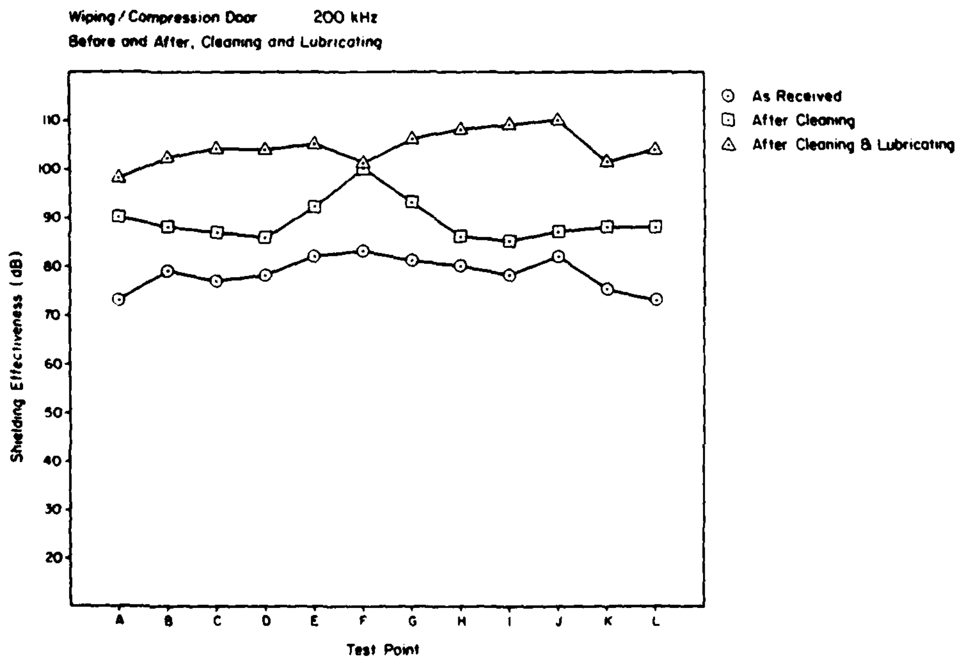


Figure 24. Shielding effectiveness of wiping/compression contact door, before and after cleaning and lubricating (200 kHz).

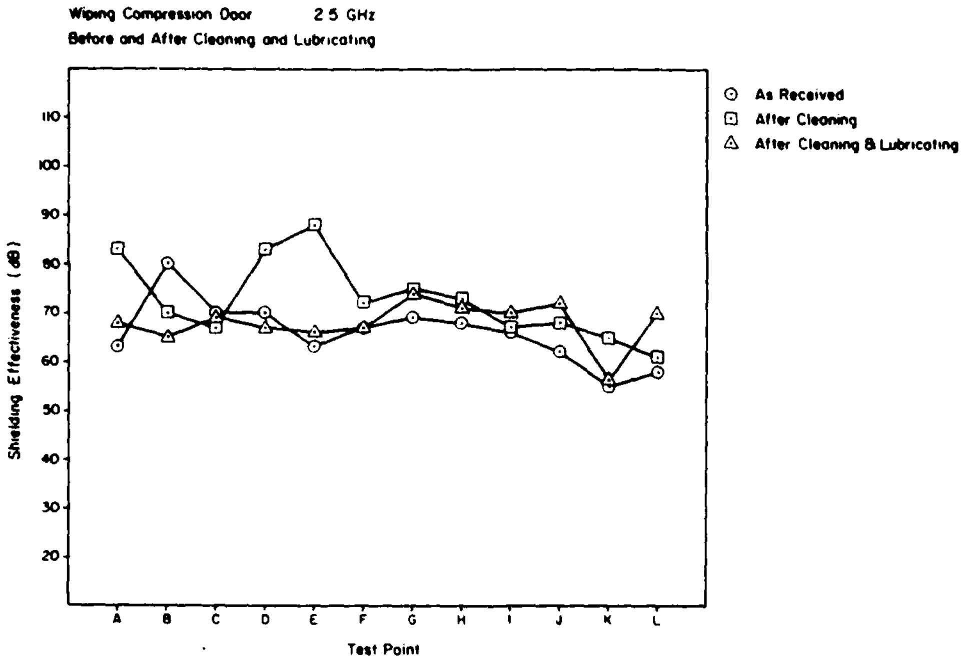


Figure 25. Shielding effectiveness of wiping/compression contact door, before and after cleaning and lubricating (2.5 GHz).

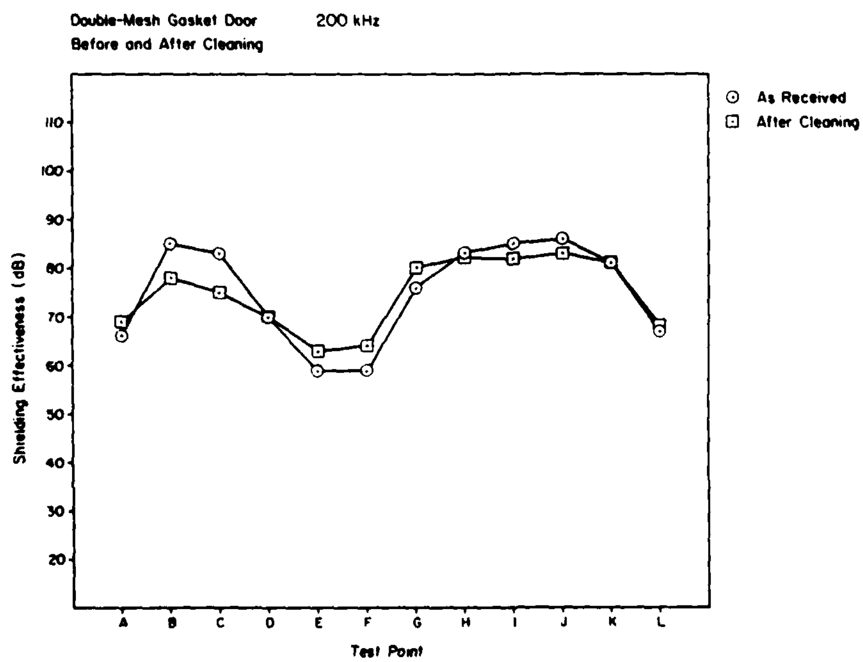


Figure 26. Shielding effectiveness of double-mesh gasket door, before and after cleaning (200 kHz).

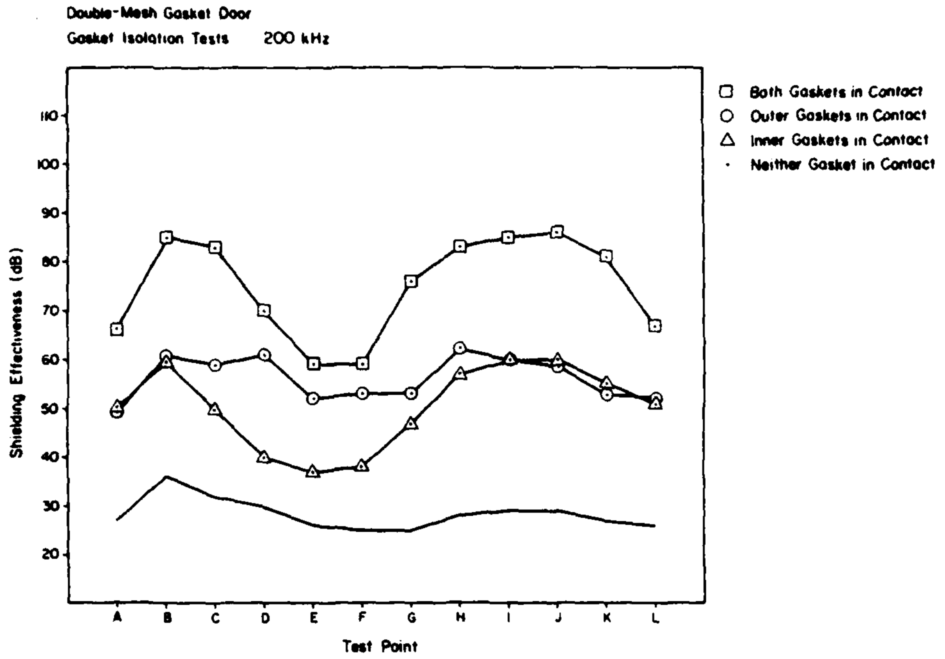


Figure 27. Shielding effectiveness of double-mesh gasket door, gasket isolation tests (200 kHz).

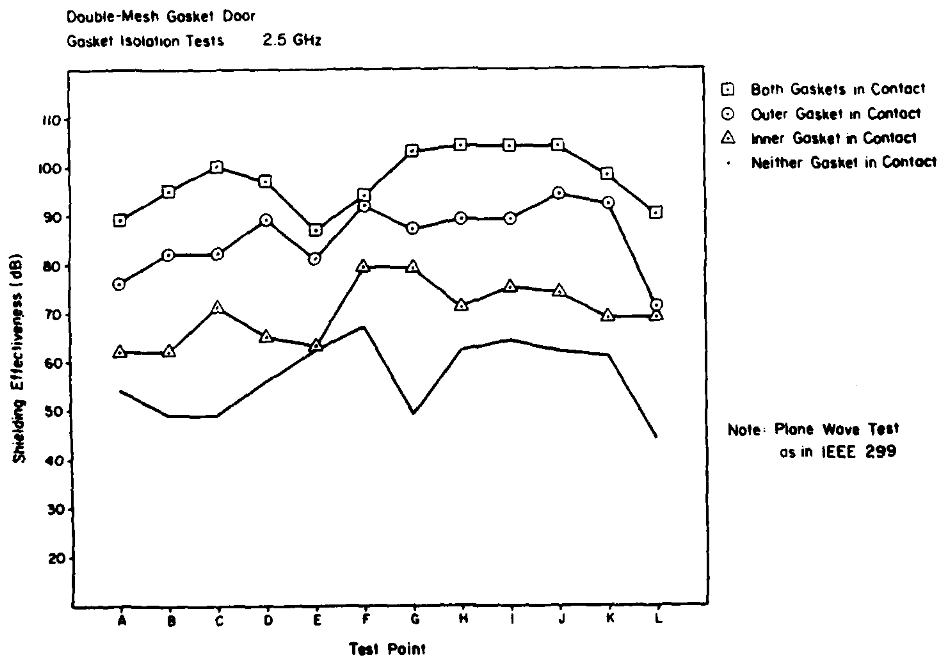


Figure 28. Shielding effectiveness of double-mesh gasket door, gasket isolation tests (2.5 GHz).

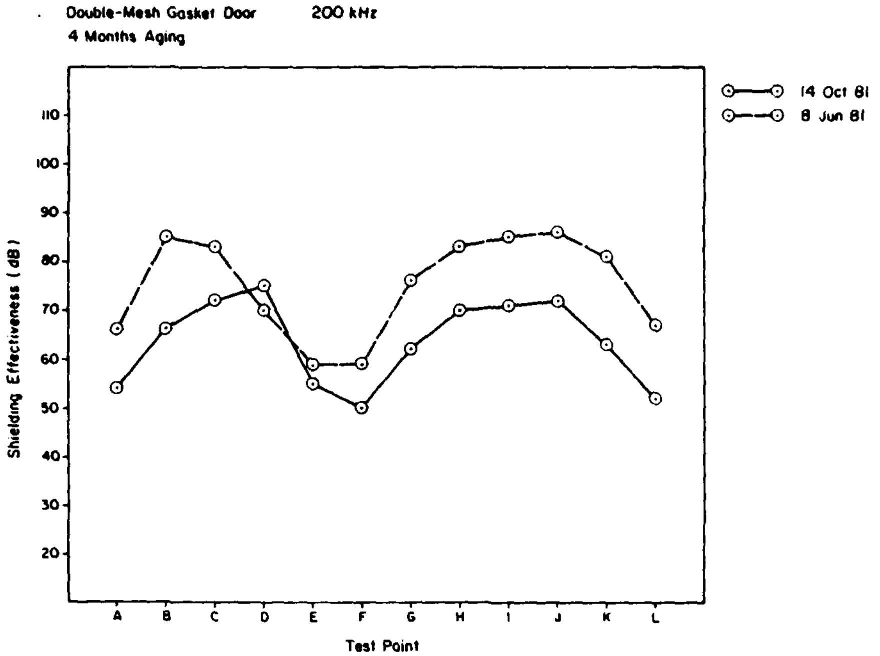


Figure 29. Shielding effectiveness of double-mesh gasket door after 4 months of aging (200 kHz).

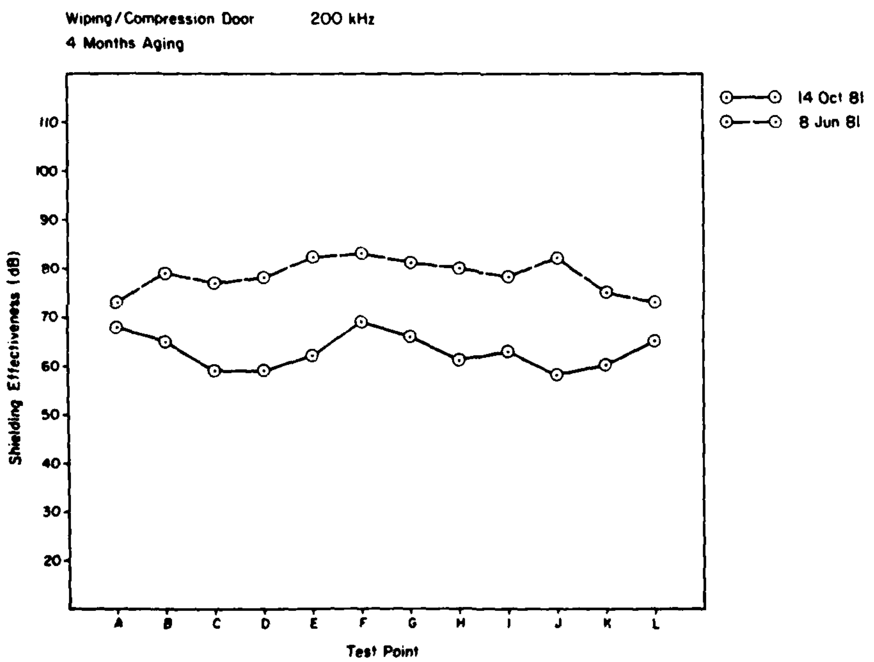


Figure 30. Shielding effectiveness of wiping/compression contact door after 4 months of aging (200 kHz).

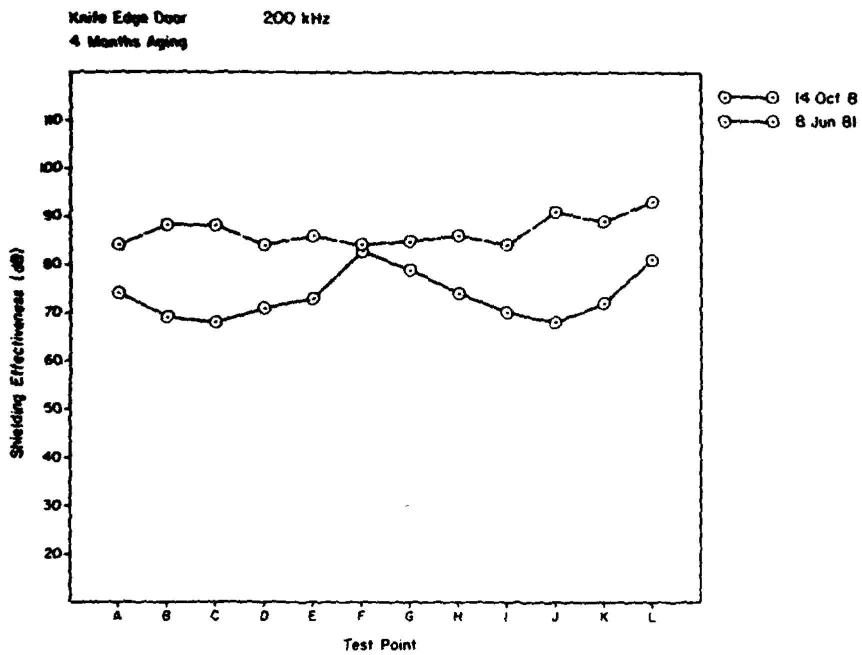


Figure 31. Shielding effectiveness of knife edge contact door after 4 months of aging (200 kHz).

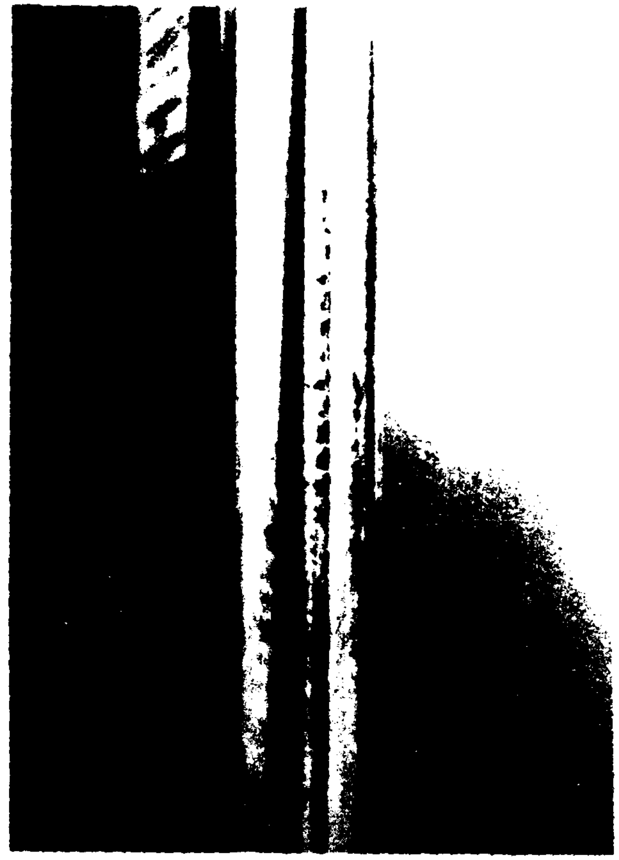


Figure 32. Residue on knife edge door after 4 months of aging.

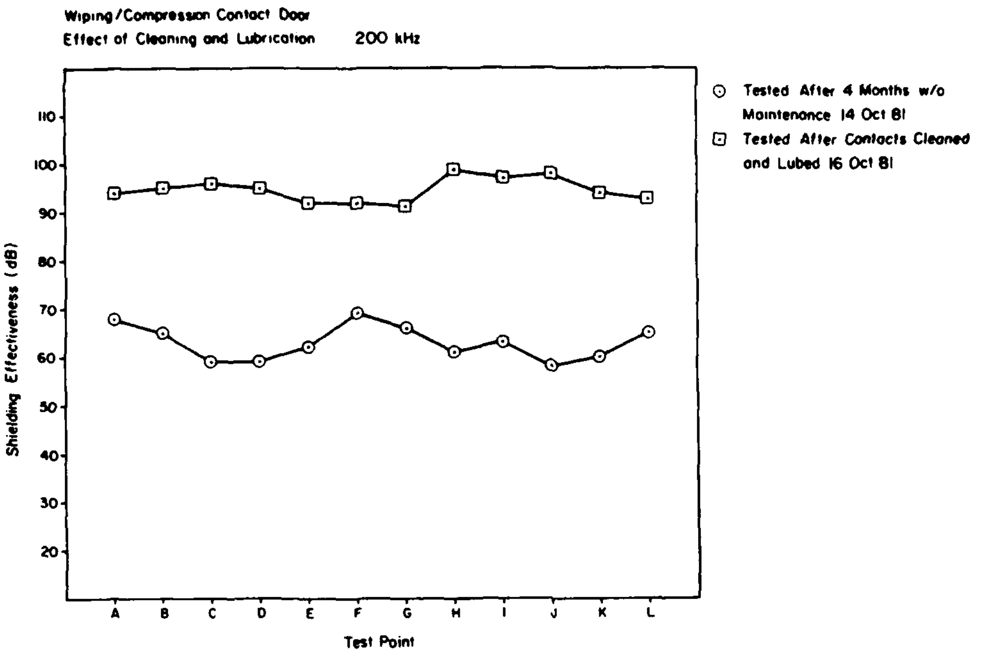


Figure 33. Shielding effectiveness of wiping/compression door, effect of cleaning and lubrication after 4 months of aging (200 kHz).

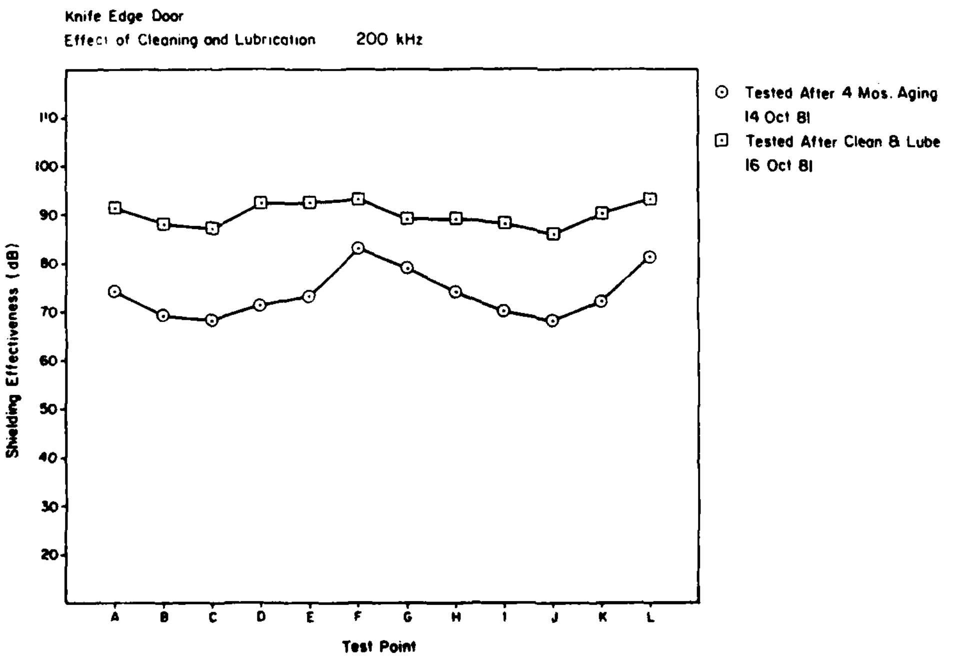


Figure 34. Shielding effectiveness of knife edge door, effect of cleaning and lubrication after 4 months of aging (200 kHz).

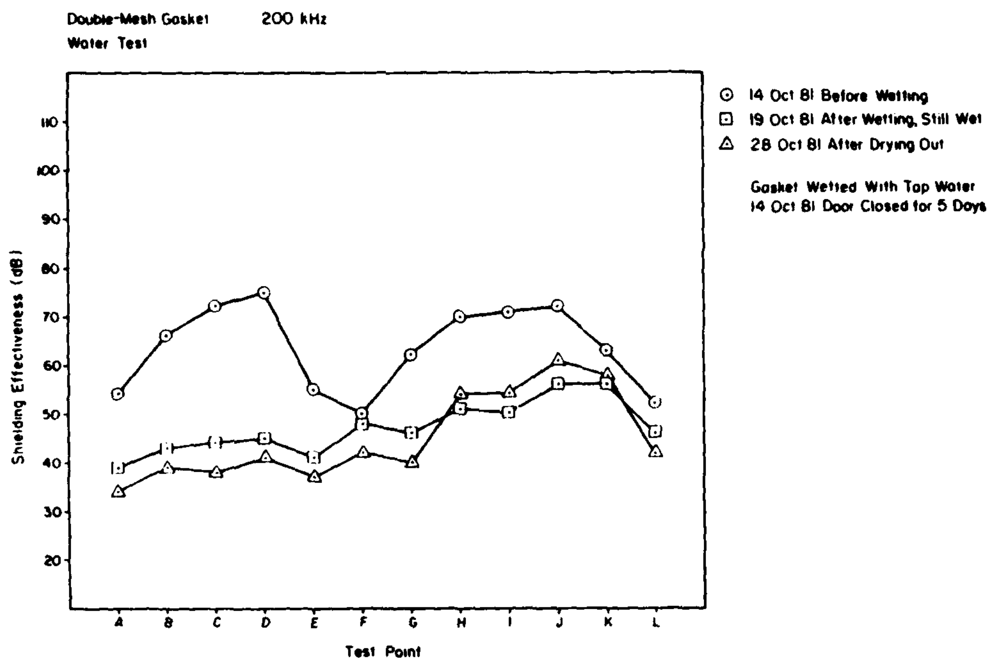


Figure 35. Shielding effectiveness of double-mesh gasket door before and after addition of water (200 kHz).

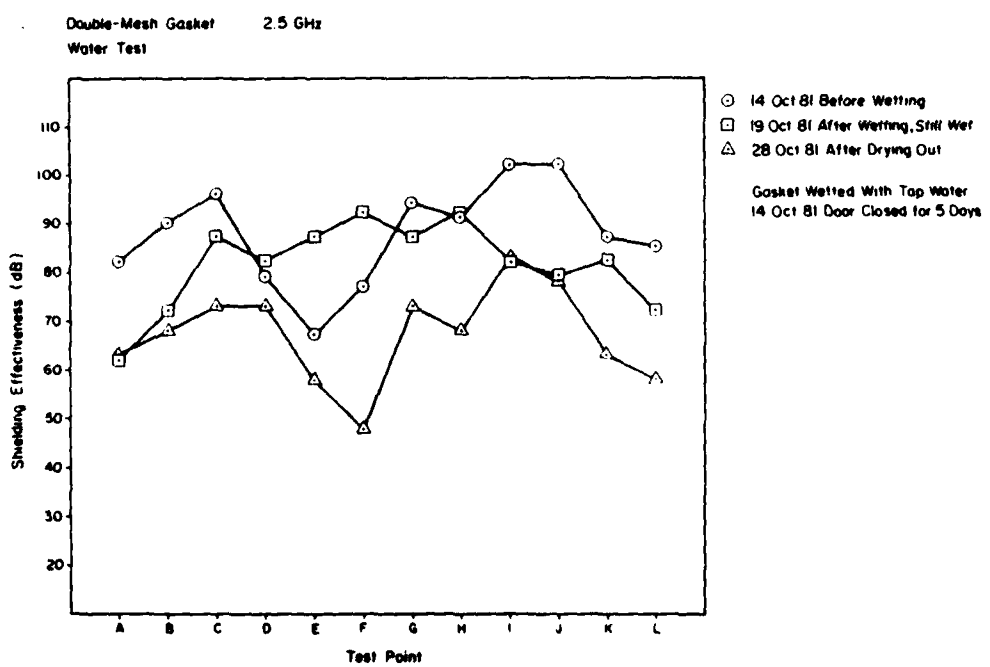


Figure 36. Shielding effectiveness of double-mesh gasket door before and after addition of water (2.5 GHz).

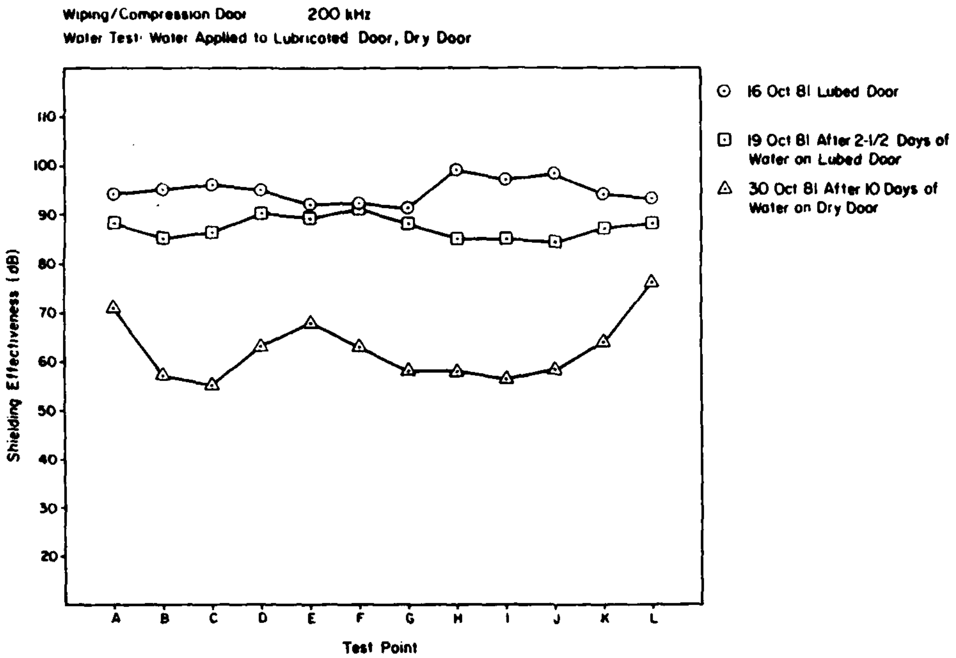


Figure 37. Shielding effectiveness of wiping/compression door, water test on lubricated and dry door (200 kHz).

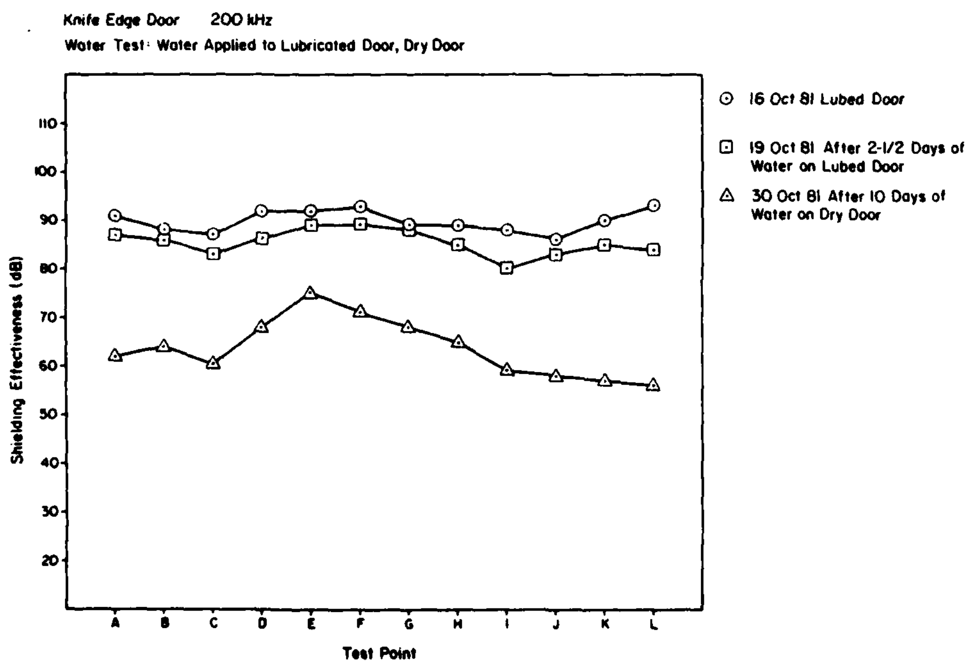


Figure 38. Shielding effectiveness of knife edge door, water test on lubricated and dry door (200 kHz).

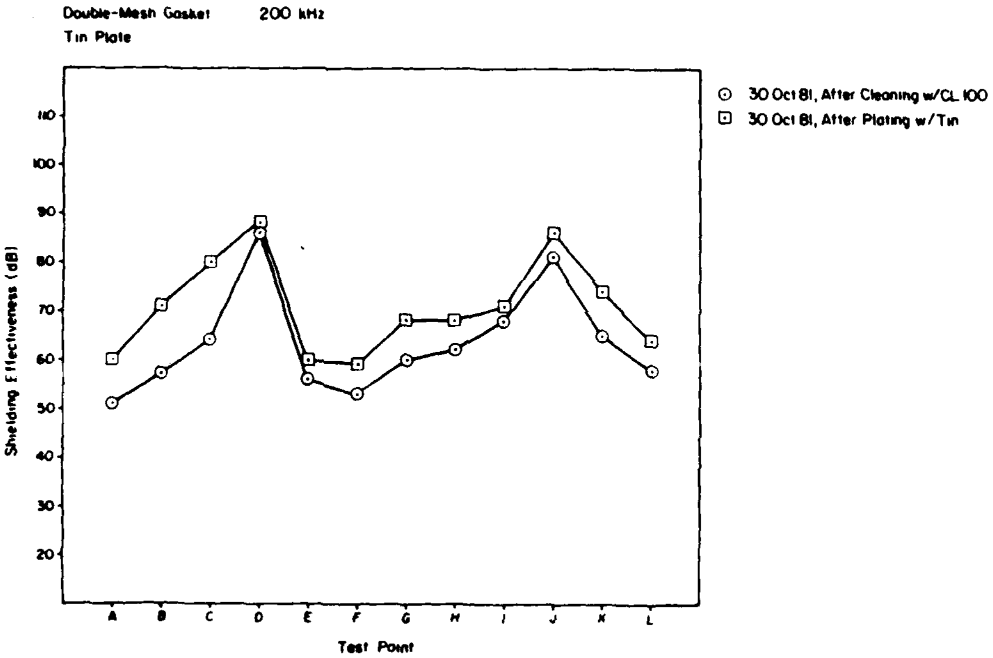


Figure 39. Shielding effectiveness of double-mesh gasket door before and after tin plating (200 kHz).

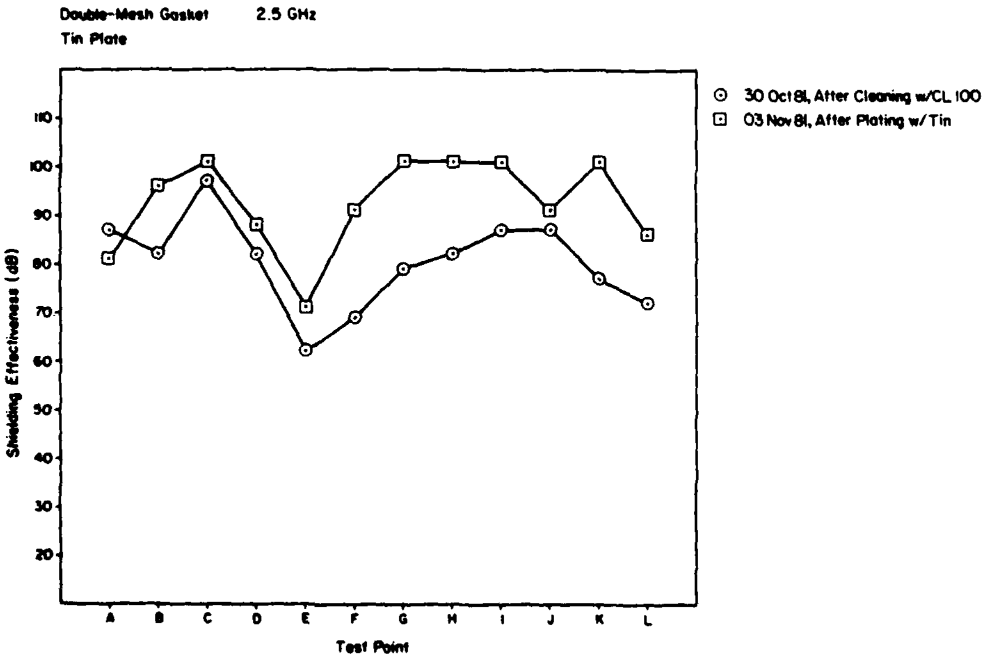


Figure 40. Shielding effectiveness of double-mesh gasket door before and after tin plating (2.5 GHz).

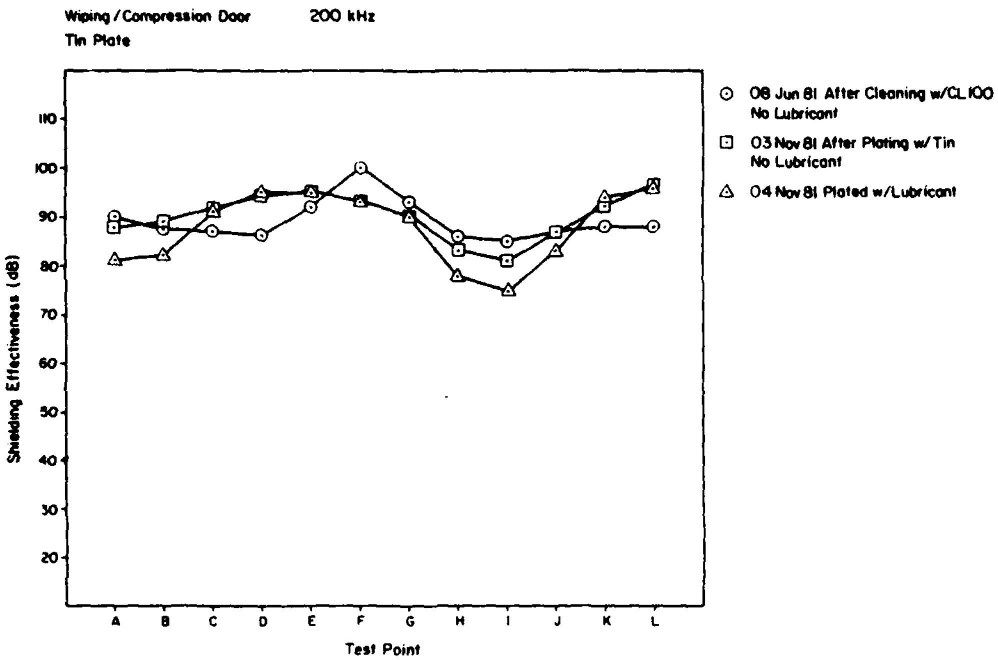


Figure 41. Shielding effectiveness of wiping/compression door before and after tin plating (200 kHz).

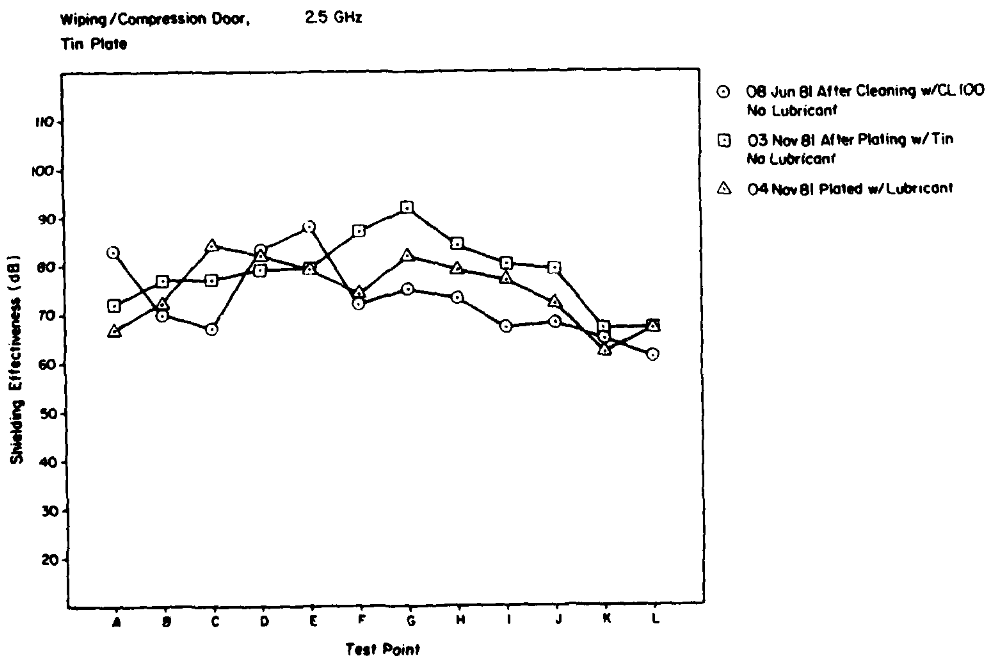


Figure 42. Shielding effectiveness of wiping/compression door before and after tin plating (2.5 GHz).

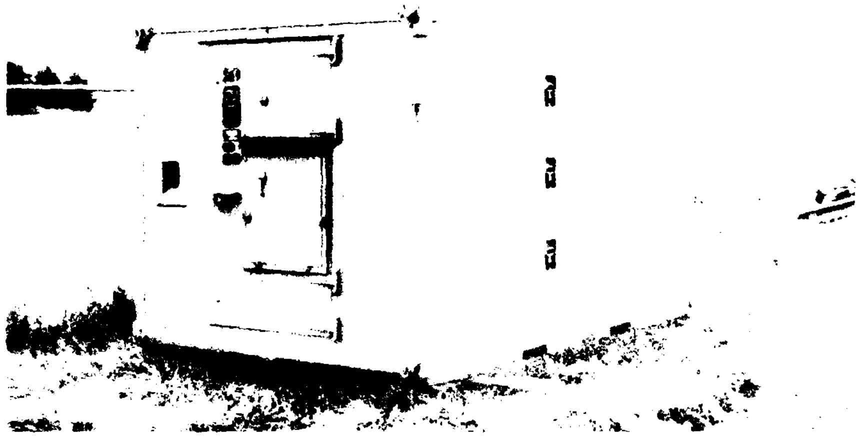


Figure A1. S-280 tactical shelter with single-mesh gasket door.

Figure A2. Single-mesh gasket door frame.

Figure A3. Single-mesh gasket door edge.

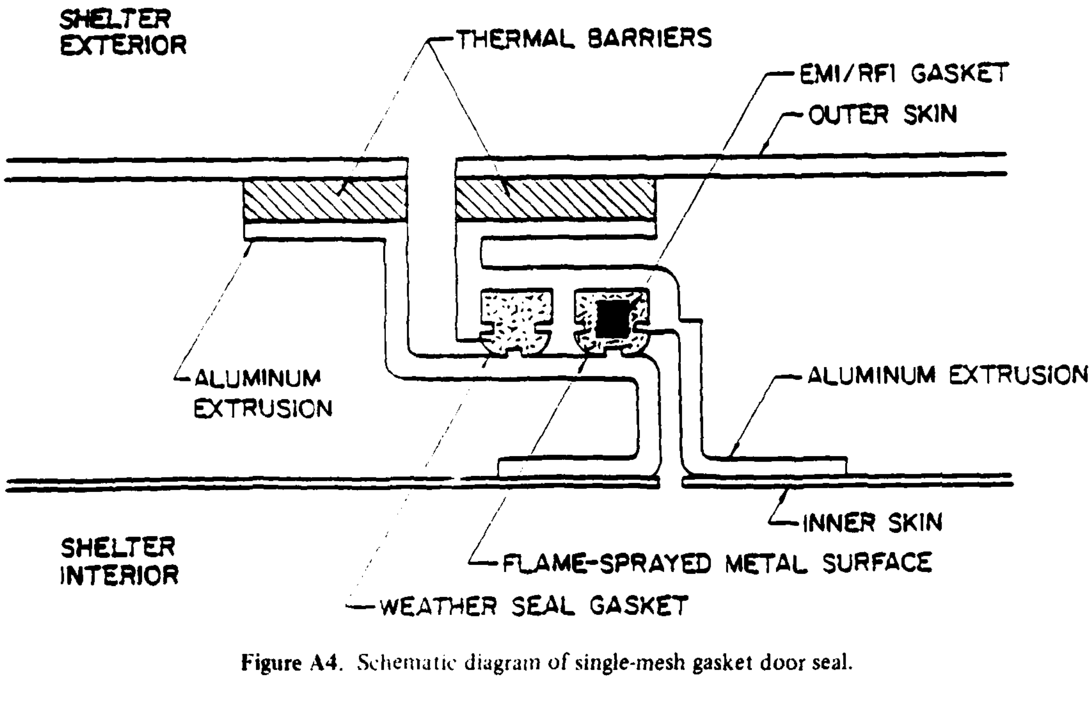


Figure A4. Schematic diagram of single-mesh gasket door seal.

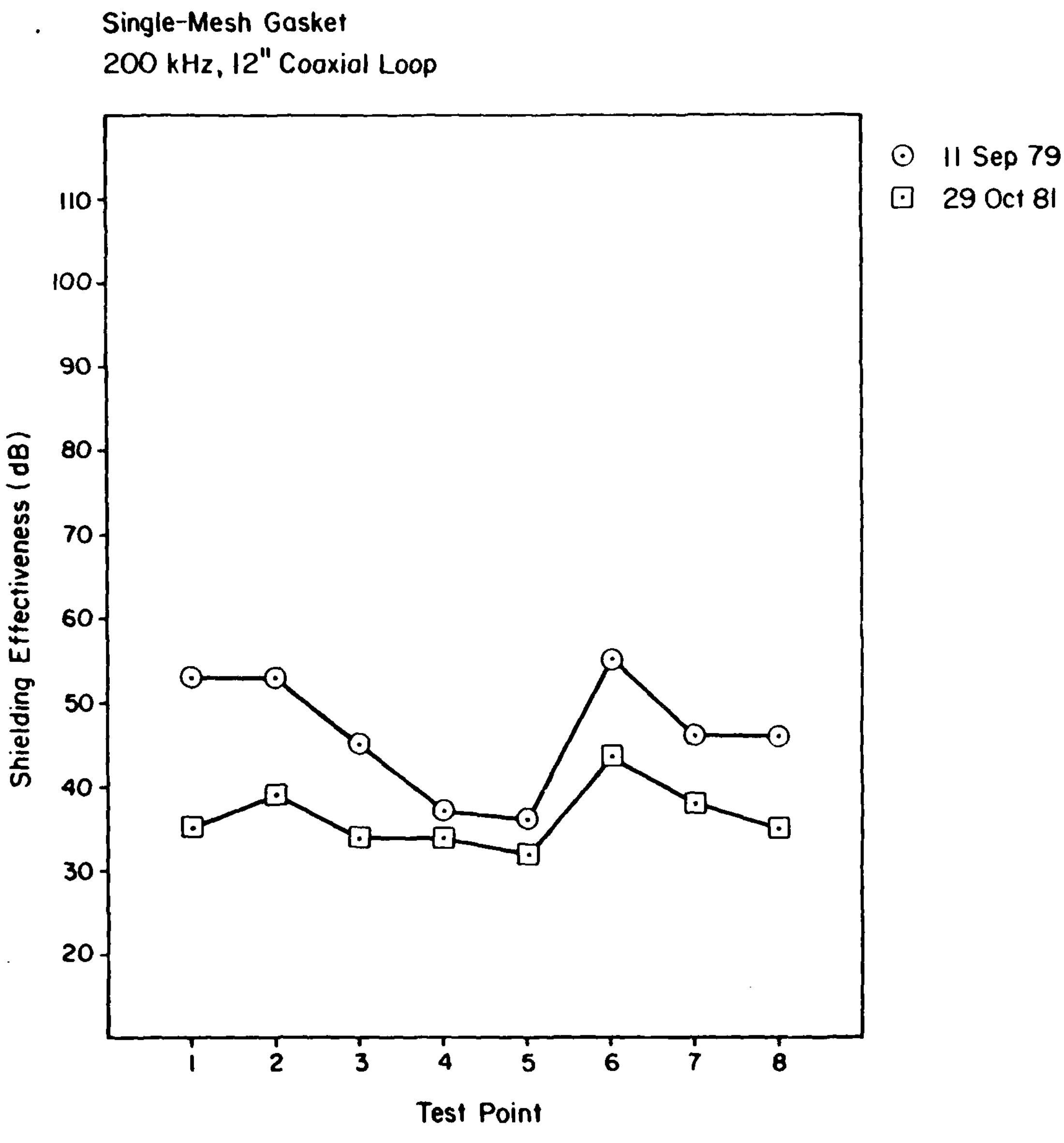


Figure A5. Shielding effectiveness of single-mesh gasket door after 2 years of aging (200 kHz).

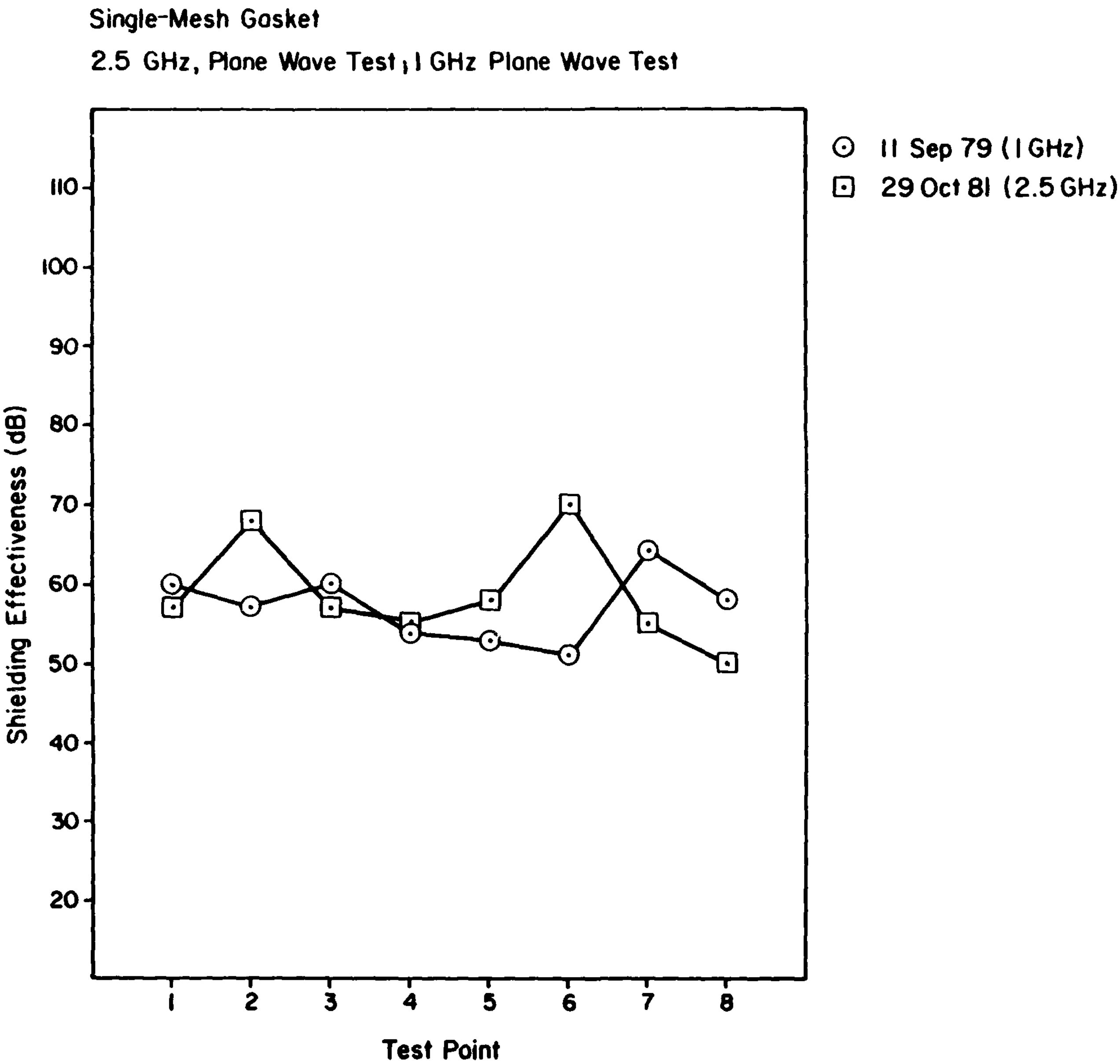


Figure A6. Shielding effectiveness of single-mesh gasket door after 2 years of aging (2.5 GHz).

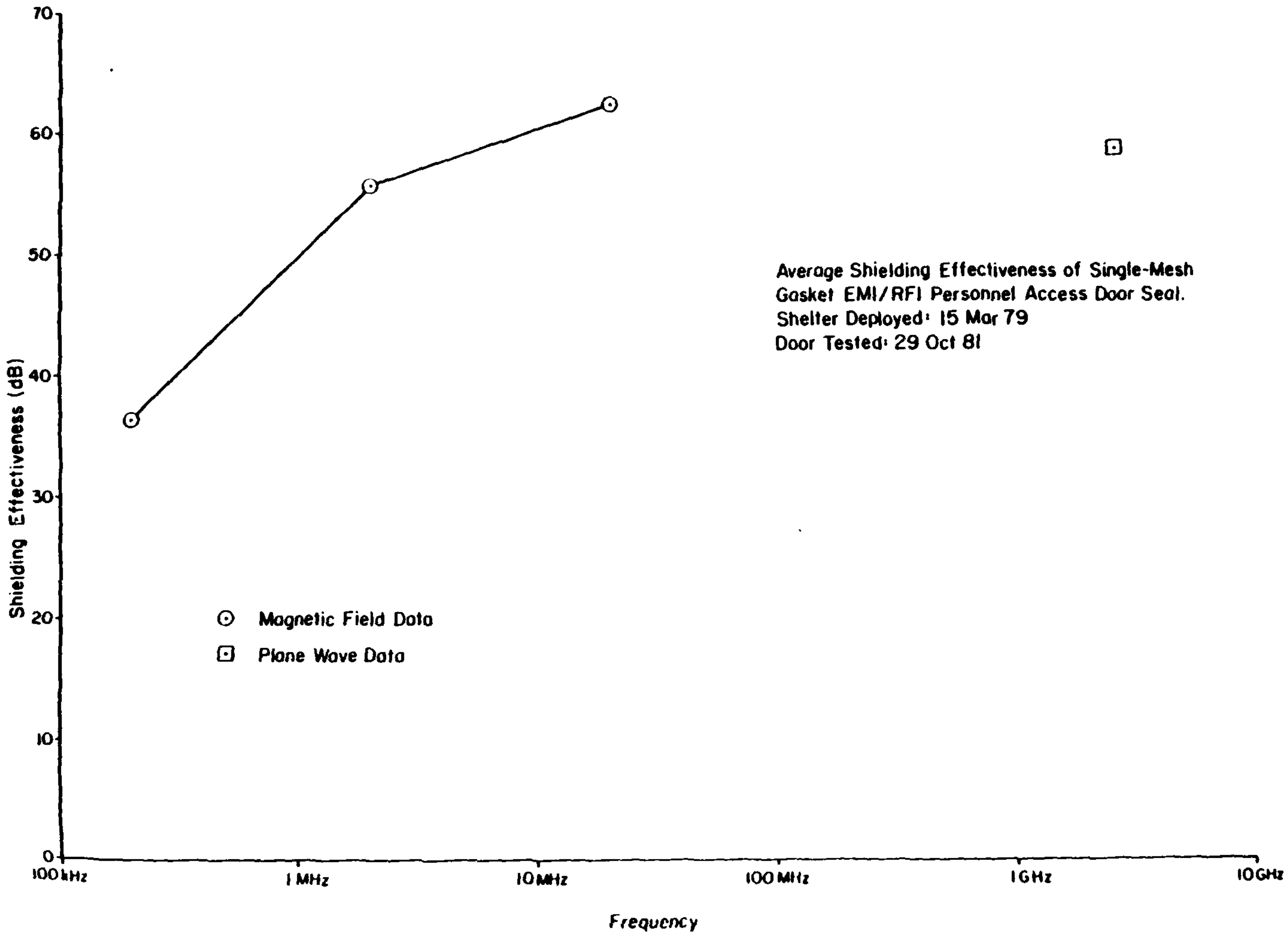


Figure A7. Average shielding effectiveness of single-mesh gasket door (200 kHz, 2 MHz, 20 MHz, 2.5 GHz).

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